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A FILTER ANALYSIS PROGRAM FOR PASSIVE SONAR SYSTEMS (USL PROGRA--ETC(U)
AUG 69 L T EINSTEIN, D M FREDERICK

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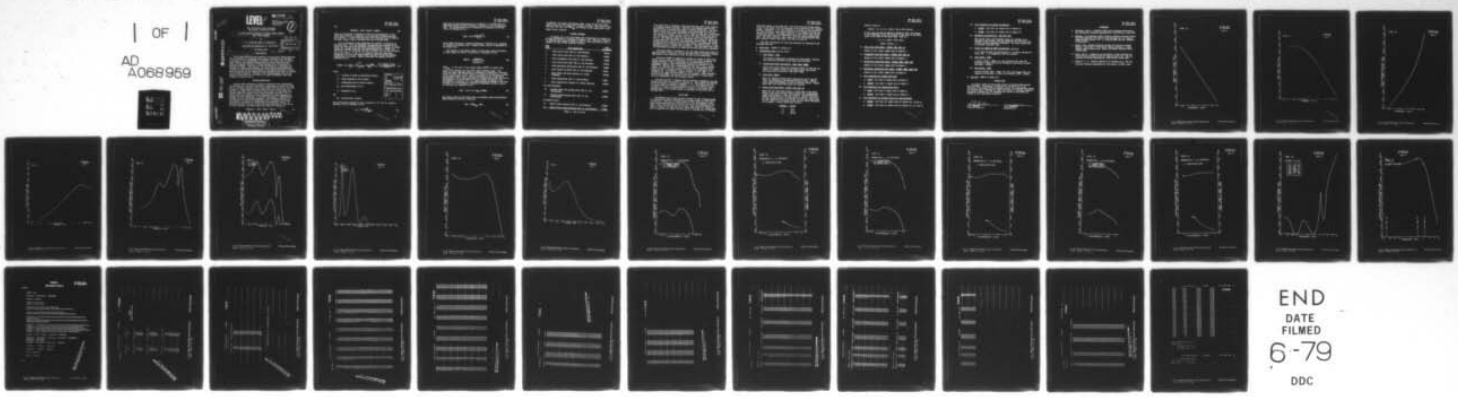

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Navy Underwater Sound Laboratory
New London, Connecticut 06320

A FILTER ANALYSIS PROGRAM FOR PASSIVE SONAR SYSTEMS (USL Program S1400)

by

L. T. Einstein and D. M. Frederick

USL Technical Memorandum No. 2070-183-69

25 August 1969

INTRODUCTION

USL Program S1400 has been written to provide sonar design engineers with a technique for selecting filter bands in passive sonar systems, in response to the requirements of reference (a). For a set of rectangular filters, the program produces plots of output signal-to-noise ratio and standard deviation of random bearing error as functions of mid-band frequency. Each set of plots corresponds to a specified combination of target, environmental, and array spectral characteristics. In addition, the detection performance of the appropriate Eckart filter, which is optimum for the particular input parameters utilized, is included as a reference standard. Features of the program design, such as the format of input data and the control of output information, have been selected for ease of use.

PROGRAM DESCRIPTION

Program S1400 represents a first-cut response to the requirements of reference (a); all input information, which might be stored in a data bank or otherwise computed, must now be provided by the user in the form of tables. These tables of source level (LS), noise level (LN), propagation loss (NW), array directivity index (NDI), and hydrophone sensitivity (NHS) are required in dB versus frequency (in kHz). It is assumed that each function is then represented by linear segments connecting the given breakpoints in the semi-log domain, a representation commonly used by sonar design engineers. The frequency domain to be investigated is selected by specifying values of minimum and maximum frequency and the number of equally-spaced intermediate points. An interpolated value for each of the five input quantities is then stored at every frequency, and input signal and noise are computed by:

$$\text{SIGNAL}(f) \quad \text{LS}(f) - \text{NW}(f) + \text{NHS}(f) \qquad (1)$$

and

$$NOISE(f) = LN(f) - NDI(f) + NHS(f) \ . \qquad (2)$$

There are situations of interest in which the representation of the input noise field by a combination of LN and NDI is neither practical nor realistic. In such cases the input sonar self-noise may be read in directly, using a flag to eliminate the use of the NDI table.

A set of desirable filter bandwidths (in octaves) is specified in the input data. For each bandwidth, calculations are performed as the filter is moved across the allowable frequency domain. Values of average signal ($\overline{S}$), average noise ($\overline{N}$), and random bearing error (SIGTH) are associated with the arithmetic mid-band frequency (F_o) for each positioning of the filter. $\overline{S}$ and $\overline{N}$ are found by using the trapezoidal integration rule over the linear signal and noise curves and properly normalizing for the band. SIGTH is specified by equation (6-36) of reference (b) as:

$$SIGTH = 5.3 \left(\frac{C}{F_o \cdot D}\right) \left(\frac{K_v^{.35}}{F^{.5} T^{.15}}\right) \left(\frac{1 + \overline{S/N}}{\overline{S/N}}\right) \sqrt{\frac{1 + 1/(50\tau)\ (S/N)}{1 + (S/N)/\tau}} \qquad (3)$$

where

C = velocity of sound in feet/second (input),

D = dipole spacing in feet (input),

T = integrating time in seconds (input),

F_o = band midfrequency in Hz,

F = bandwidth in Hz,

and

K_v = velocity gain constant.

The velocity gain constant is also a function of $\overline{S}$ and $\overline{N}$, given in equation (5-2) of reference (b) as:

$$K_v = 6.67\left(\frac{\overline{S/N}}{1 + \overline{S/N}}\right) \ . \qquad (4)$$

Each value of random bearing error is compared to a computed gate to determine whether automatic tracking is feasible at the corresponding $\overline{S/N}$. The tracking gate limit is specified by equations (4-39) and (7-2) of reference (b) as:

$$GATE = \sin^{-1}\left(\frac{2.0 \cdot C \cdot 10^{-4}}{F_o \cdot D}\right) . \qquad (5)$$

Since SIGTH represents a standard deviation of bearing error, tracking is considered acceptable when $3 \cdot SIGTH \leq GATE$, and is so indicated on the output plot.

The response of the Eckart filter for each case, given the spectra of input signal and noise, is specified in reference (c) by:

$$ECK(f) = \frac{SIGNAL(f)}{[NOISE(f)]^2} . \qquad (6)$$

$(\overline{S/N})_{ECK}$ is the ratio of the output signal (S^2/N^2) to output noise (S/N), both averaged over the entire input frequency range. The effective signal bandwidth (BWS) is determined by finding the frequency limits (in kHz), F1S and F2S, which are located at the half-power points of the output signal curve. This is considered to be a rough first approximation, and an improved method for determining F1S and F2S will be incorporated in a second version of this program, according to the development in reference (d). For passive detection systems of the type proposed, the corresponding recognition differential (in dB) is given in reference (e), equation II, as:

$$NRD = -19.7 - 5.0 \log_{10} (6 \cdot BWS) . \qquad (7)$$

The signal excess (in dB) which would be available using the particular Eckart Response function is given by:

$$NXS = (\overline{S/N})_{ECK} - NRD . \qquad (8)$$

In addition, the signal midfrequency (FMS), which divides the output signal curve into two equal power regions, is found. The values of F1S, F2S, FMS, NRD, NXS, and $(\overline{S/N})_{BCK}$ are printed on the output plot of the Bokart filter response.

PROGRAM FEATURES

A complete set of all plots which can be generated by a single set of input information is presented in Figures 1-17. There are a total of 13 different plot types, as shown in Table I, with plot types 10 and 11 repeated for each filter bandwidth selected.

PLOT TYPE	PLOT DESCRIPTION	PLOT INDICATORS
1	Input Source Level (dB) vs. Log Frequency	PLOTLS
2	Input Noise Level (dB) vs. Log Frequency	PLOTLN
3	Input Propagation Loss (dB) vs. Log Frequency	PLOTNW
4	Input Directivity Index (dB) vs. Log Frequency	PLOTDI
5	Input Hydrophone Sensitivity (dB) vs. Log Frequency	PLOTHS
6	Input Signal and Noise (dB) vs. Log Frequency	PLOTN
7	Input Signal and Noise (linear) vs. Linear Frequency	LPLOTN
8	Input Signal/Noise (dB) vs. Log Frequency	PLOTR
9	Input Signal/Noise (linear) vs. Linear Frequency	LPLOTR
For each bandwidth:		
10	Average Signal and Average Noise (dB) vs. Log Midfrequency	PLOTAN
11	Average Signal/Average Noise (dB) vs. Log Midfrequency	PLOTAR
For Bokart filter:		
12	Bokart Filter Response (dB) vs. Log Frequency	PLOTBF
13	Bokart Filter Signal Response (dB) vs. Log Frequency	PLOTBS

Table I: List of Plots

It is clear that a parametric study involving many cases could generate a tremendous number of graphs. Therefore, two program features have been included to minimize the volume of plotted information. The first feature is the use of plot indicators in the input data to allow the user to select only those plots which he needs in each case. Since cases will differ by a change in one or more of the five primary data tables, the corresponding plot indicator must be set nonzero as each table is fed in. The remaining eight plot indicators will retain the values set in the first case, unless the user purposely reorders them. The second program feature is the use of subroutine OPXLOG to automatically reduce the extent of the frequency axis, in each of the semi-log plots, to the minimum required to present the information. This subroutine also draws the logarithmically-spaced tic marks and provides appropriate labelling.

Subroutine GRAPH is designed to plot the input break-point tables on semi-log graphs, taking into account the shift made by subroutine OPXLOG. Appropriate y-axis labelling is also provided by this subroutine.

Subroutine INTERP is designed to operate on a table of break-point values, such as those described above for the five input variables, to produce dependent values corresponding to an equally-spaced set of independent values. The interpolation equation is controlled by two indicators, INDX and INDY, corresponding to plot axes x and y, respectively. An indicator set to zero means that the corresponding break-point variable is plotted linearly; a value of one indicates a logarithmic plot. For example, a choice of INDX = 1 and INDY = 0 is needed for the semi-log input tables of this program. After extraction by subroutine INTERP, the levels in dB are converted to linear units prior to integrating over the frequency domain.

The input deck for a typical case is presented in Appendix A and the printout for this case is given in Appendix B. This printout corresponds to the information contained in Figures 1 - 17. The running time for this case, where the frequency interval of 0.5 to 10.0 kHz was covered in steps of .1 kHz, was approximately 35 seconds on the Univac 1108. Program S1400 in its current version is available on the first file of CUR tape U453.

INPUT DECK

The NAMELIST data format has been selected for this program because it presents the greatest flexibility and minimum number of restrictions for the user. There are no fixed format or order requirements on the data cards within each case structure, except for the beginning and end cards. Minor restrictions are as follows: each record card must not start in column 1 and must end with a comma; data items on a single card must be separated by commas; and the name of a variable and its assigned

value must appear on the same card. The first case must assign values to all of the inputs, with the exception of plot indicators for undesired graphs. Thereafter, it is only necessary to provide, in the data cards of a case structure, those values which are to be changed from the preceeding case inputs. The single exception to this rule is the setting of the five input data plot indicators, which are zeroed between each case. The usual procedure, then, would be to set the appropriate data plot indicator nonzero each time a new table is read in.

The input information for each case structure is contained in the following card set.

A. First card - $INPUT in columns 2-7.

B. Intermediate cards (in any order) -

1. Case number: CASE

   The program automatically increments the case number, starting from the value specified in any input case structure.

2. Interpolated table descriptors: FMIN, FMAX, NFREQ

   These three values define the frequency bounds (in kHz) and the number of frequency points in the interpolated input table. All values must be positive, with FMIN < FMAX.

3. Noise flag: NFLAG

   This is a logical variable which controls the use of the NDI table, as described in "Program Description" above. NFLAG = .TRUE. means that NOISE(f) is read in directly; NFLAG = .FALSE. means that both *LN* and NDI tables are required.

4. Source level data table: PLOTLS, NLS, FLS, LS

   There are five input data tables, of which this is the first. PLOTLS is the plot indicator which produces the corresponding output graph (Figure 1) when set non-zero. NLS specifies the number of value pairs in the data table to follow. FLS and LS are the tabulated values of frequency (in kHz) and source level (in dB), which must be punched in the order of their subscripts. As an example, a source level table such as:

FLS(kHz)	LS(dB)
.5	90.0
.8	95.8
1.0	101.45

would be coded as:

FLS(1) = .5, .8, 1.0, LS(1) = 90.0, 95.8, 101.45, .

If more than one card is needed to present a list, the integer in the parenthesis tells the location in the table of the first value to the right of the equal sign. That is,

---------, LS(1) = 90.0, 95.8,

LS(3) = 101.45, --- .

5. Noise level data table: PLOTLN, NLN, FLN, LN

   Similar to (4), above; sample plot in Figure 2.

6. Propagation loss data table: PLOTNN, NNN, FNN, NN

   Similar to (4), above; sample plot in Figure 3.

7. Directivity index data table: PLOTDI, NNDI, FNDI, NDI

   Similar to (4), above; sample plot in Figure 4.

8. Hydrophone sensitivity data table: PLOTHS, NNHS, FNHS, NHS

   Similar to (4), above; sample plot in Figure 5.

9. Plot indicators for signal and noise:

   a. PLOTN - plot type 6; sample plot in Figure 6.

   b. LPLOTN - plot type 7; sample plot in Figure 7.

10. Plot indicators for signal/noise ratio:

    a. PLOTR - plot type 8; sample plot in Figure 8.

    b. LPLOTR - plot type 9; sample plot in Figure 9.

11. Plot indicators for average values for each bandwidth:

    a. PLOTAN - plot type 10; sample plots in Figures 10, 12 and 14.

    b. PLOTAR - plot type 11; sample plots in Figures 11, 13, and 15.

12. Plot indicators for Eckart information:

a. PLOTEF - plot type 12; sample plot in Figure 16.

b. PLOTES - plot type 13; sample plot in Figure 17.

13. Bandwidth specifications: MIN, MAX, DEL:

MIN and MAX define the bandwidth limits (in octaves) to be analyzed by the program, and DEL determines the difference (in octaves) between successive bandwidths. All three values must be positive, with MIN $\leq$ MAX.

14. Values for SIGTH and GATE calculations: C, D, T:

C is sound velocity (in feet/second), D is dipole spacing (in feet), and T is integration time (in seconds).

15. Skip option: SKIP:

A value of SKIP = .TRUE. in a case structure will omit the execution of that case and all successive cases until an input with SKIP = .FALSE. .

16. Stop option: STOP:

Logical variable STOP = .TRUE. will stop the program after the execution of the case; if this is not desired, STOP = .FALSE. .

C. End card - $END in columns 2-5.

FUTURE PLANS

At present, plans for the second version of Program S1400 include the following: (1) applying the approach of reference (d) to the selection of the Eckart filter frequency limits; (2) investigating methods for storing and/or computing the input data tables to simplify parametric performance studies; and (3) including the effects of non-linear processing in the beamforming simulation.

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D. M. Frederick

D. M. FREDERICK
Mathematician

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a. Soderberg, John W., "An/BQS-13 IDMA Analog Tracking Improvements," USL Confidential Technical Memorandum No. 2113-069-69, 14 May 1969.

b. Raytheon, "An Analytical Study of Factors Limiting Automatic Target Following Operation with Passive Sonar Equipment at Low Acoustic Signal-to-Noise Ratios," Vol. I, 16 March 1968, USL Acc. 34909-F-1 (Confidential).

c. Eckart, Carl, "Optimal Rectifier Systems for Dection of Steady Signals," University of California, Scripps Institute of Oceanography, Marine Physics Lab., Report SIO 12698, Reference 52-11, 4 March 1952.

d. Pratt, John R., "Comparison of the Effects of Band Limiting and Reverberation Limiting on Passive Figure of Merit (U)," USL Confidential Technical Memorandum No. 2113-063-69, 23 May 1969.

e. Magaraci, A. F., "General Equations for Computing N_{RD}," USL Confidential Technical Memorandum No. 2111-012-68, 24 April 1968.

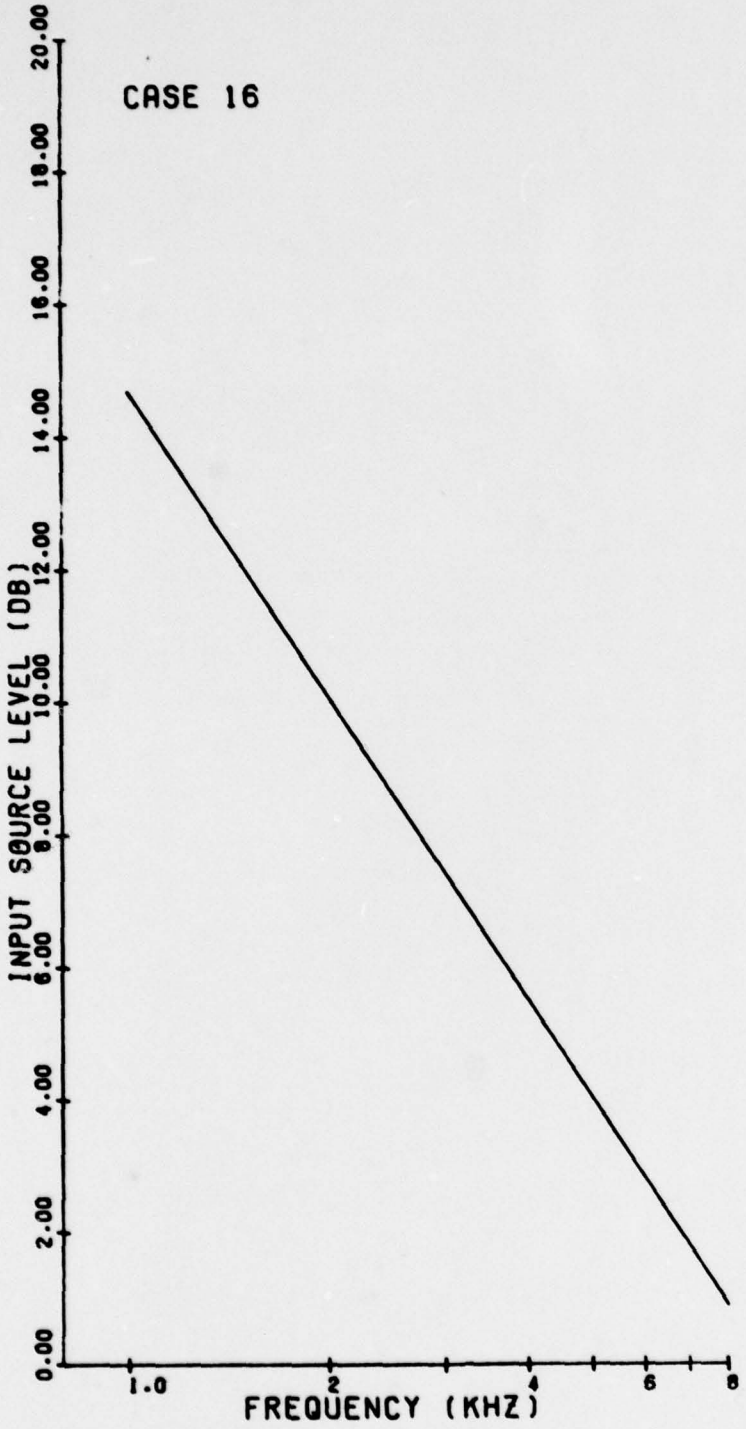

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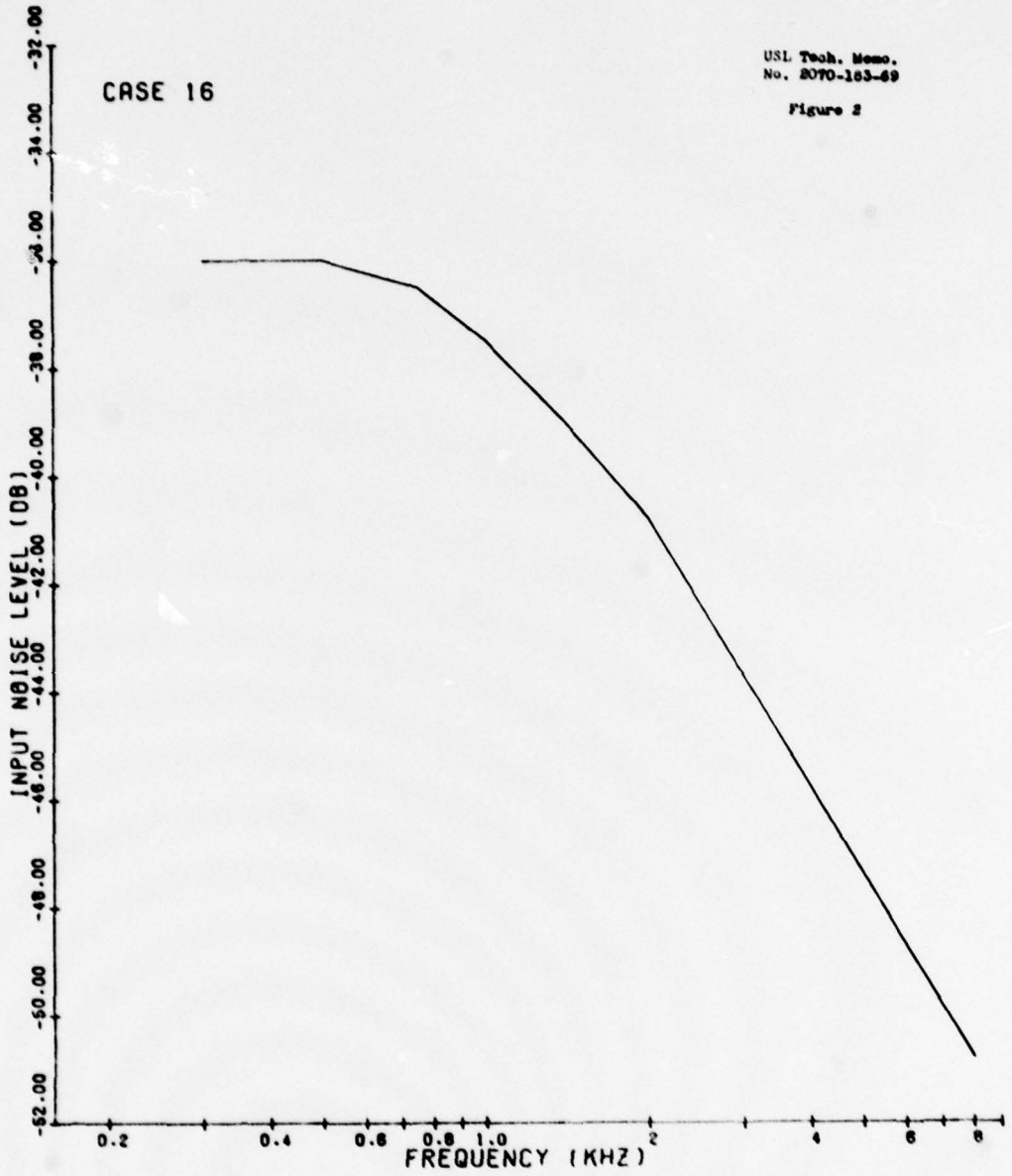
Figure 2

CASE 16



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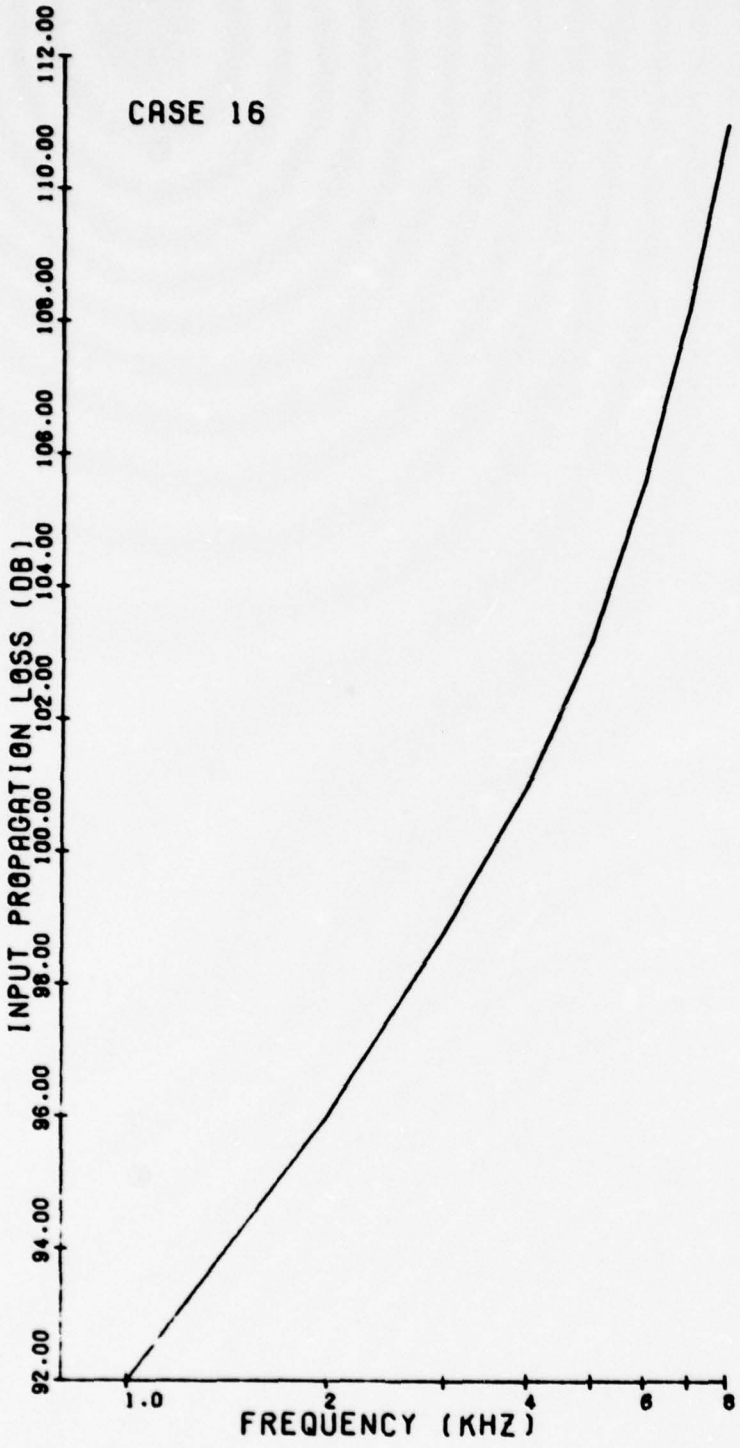

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Figure 3

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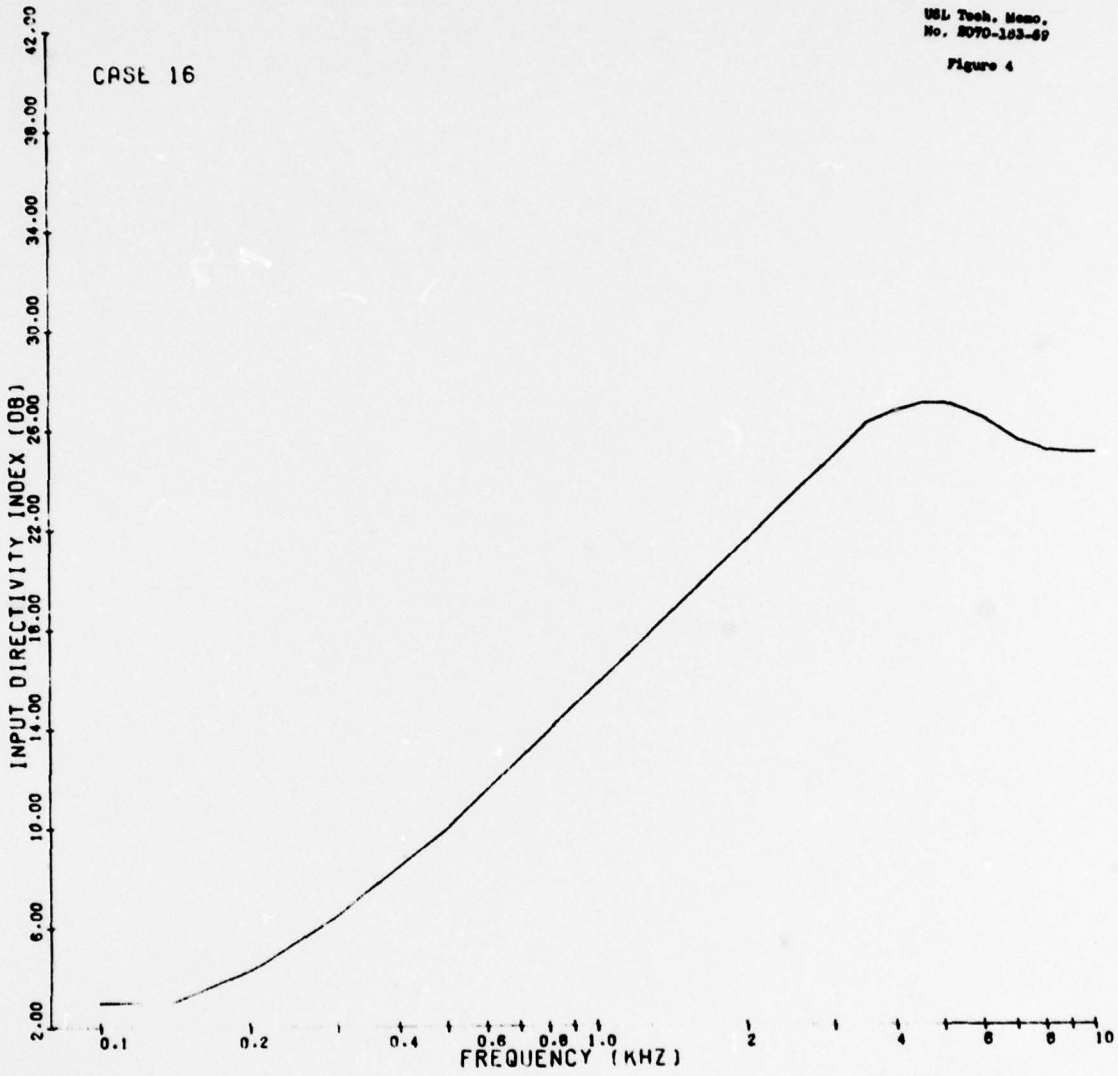
Figure 4

CASE 16



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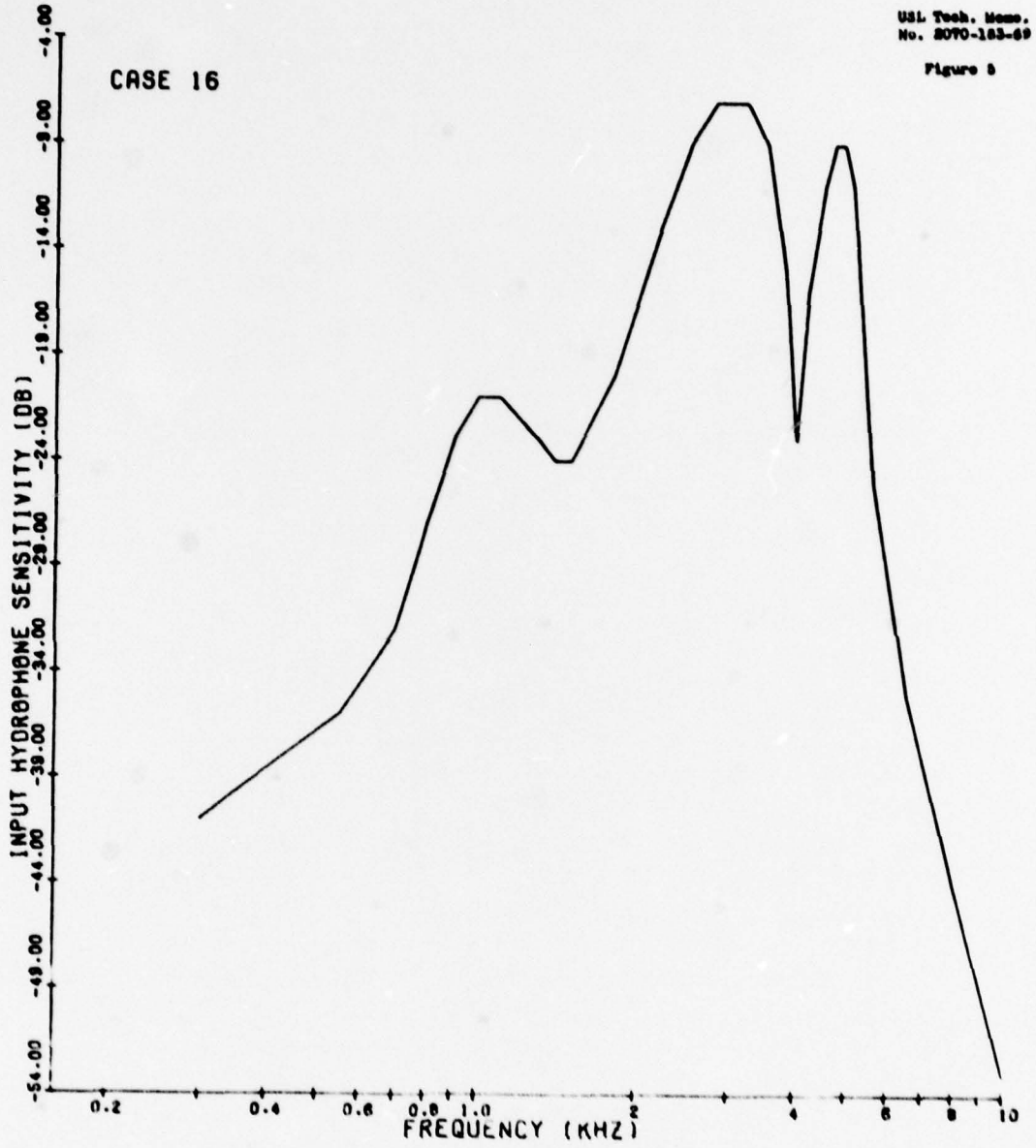

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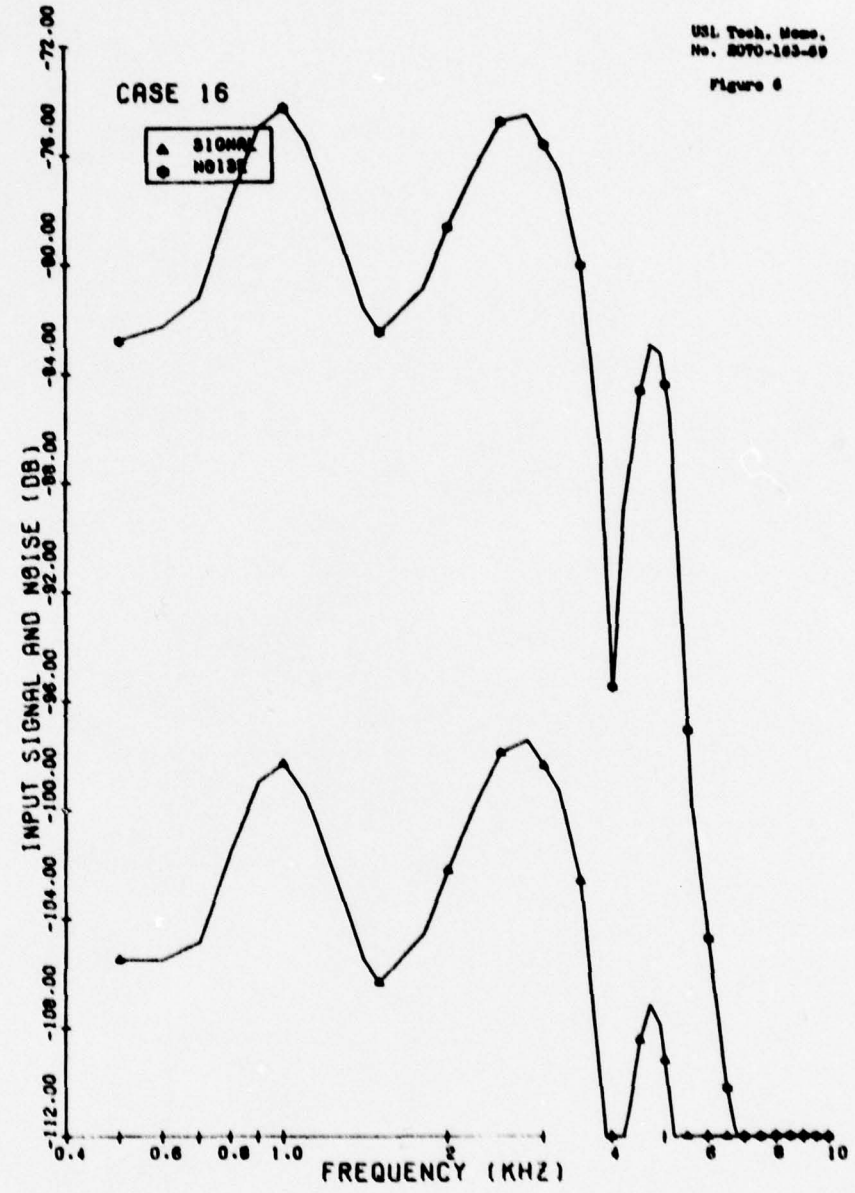

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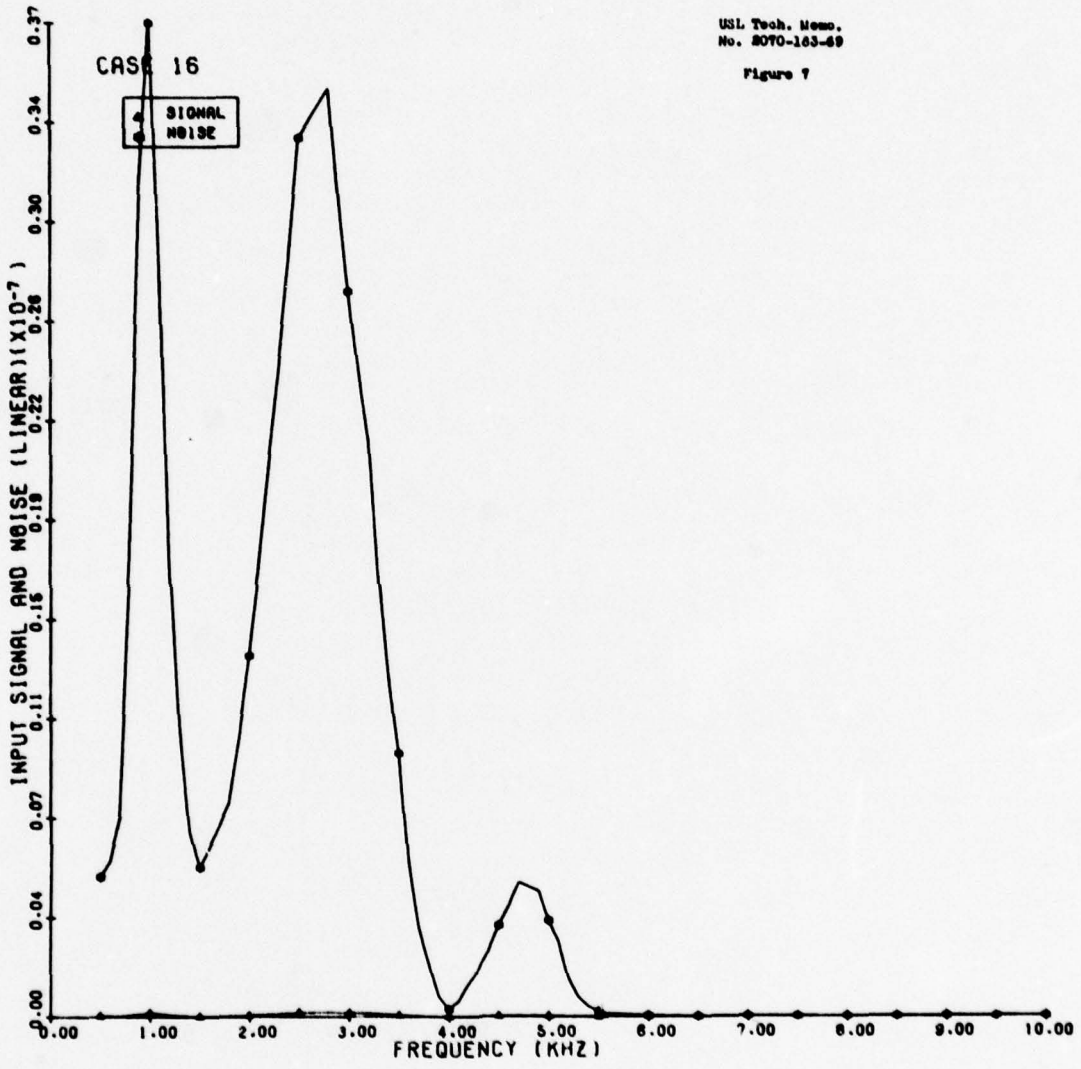

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Figure 6

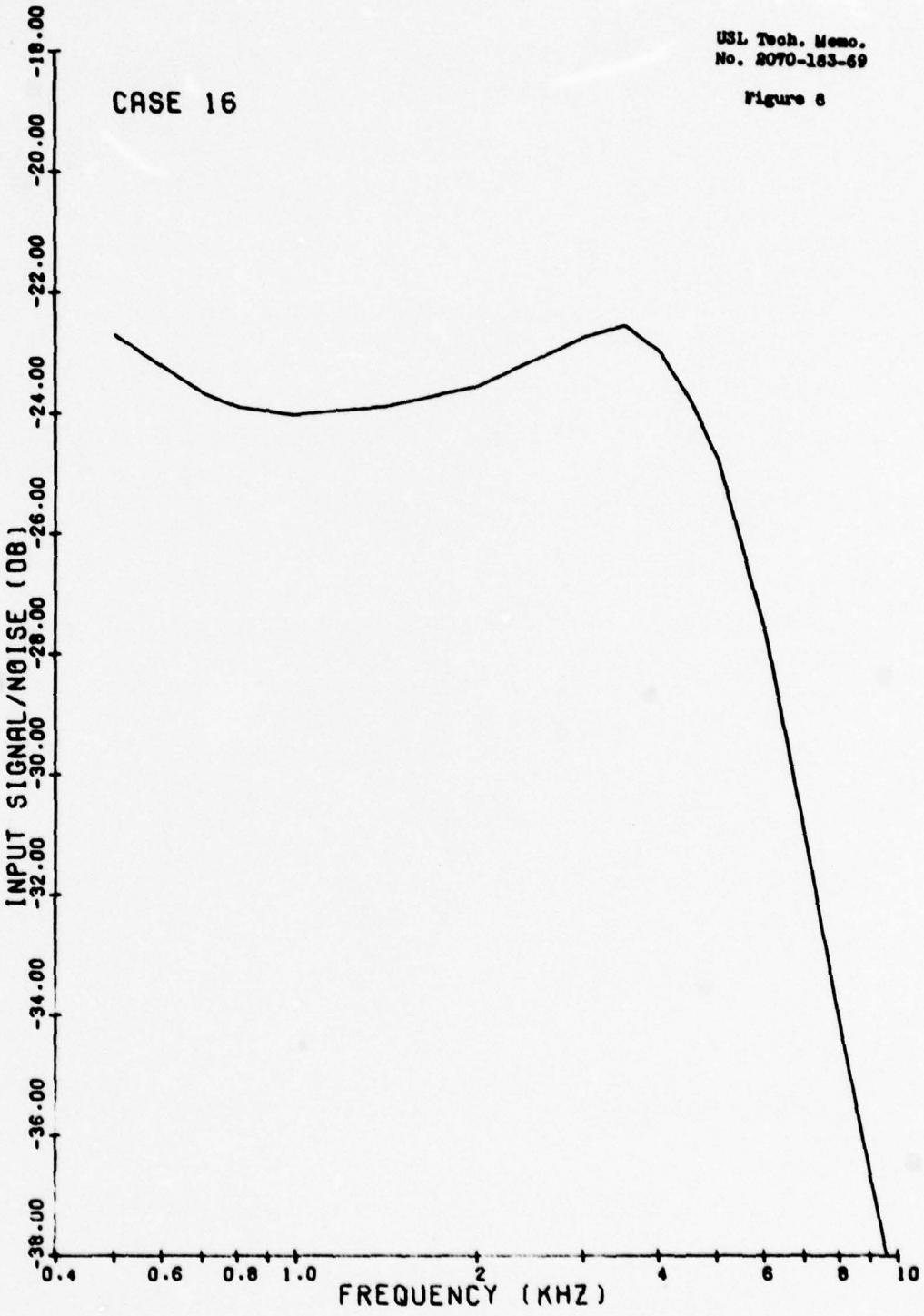

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Figure 9

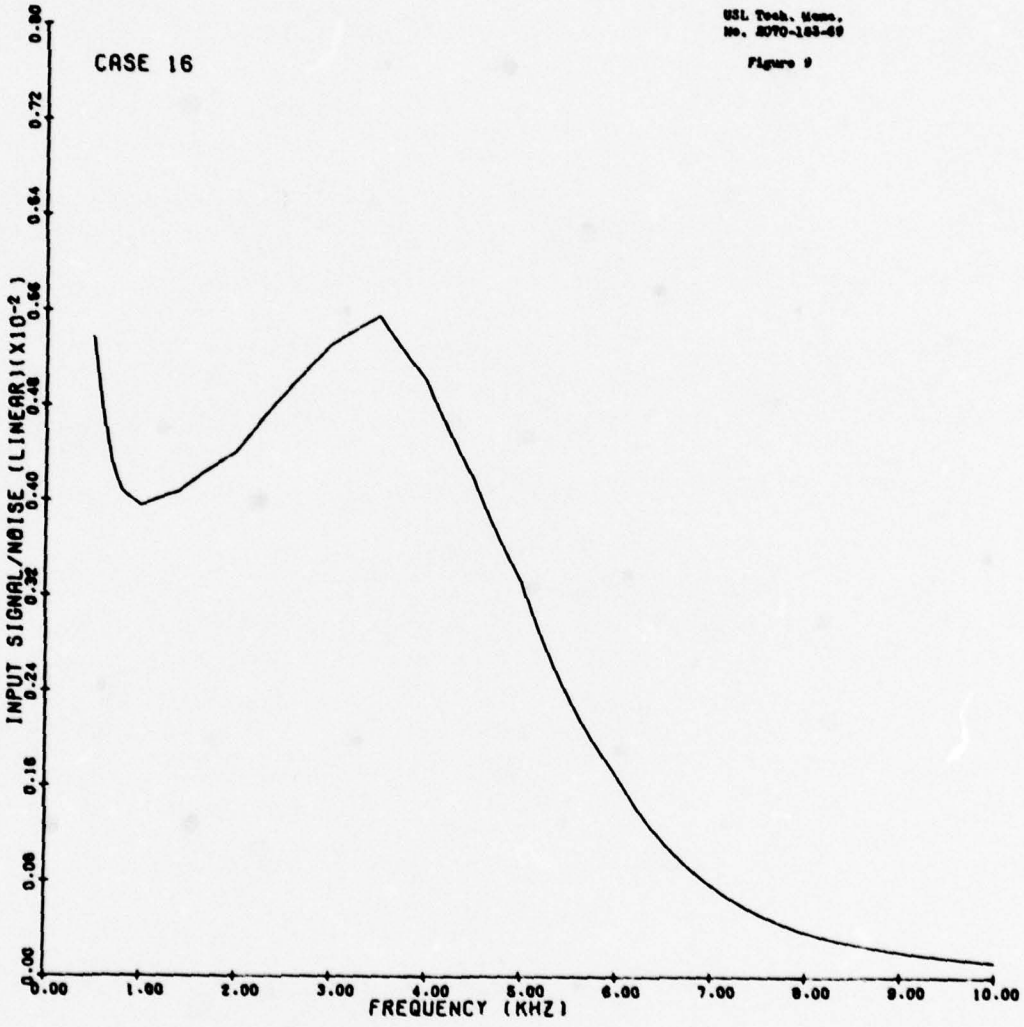

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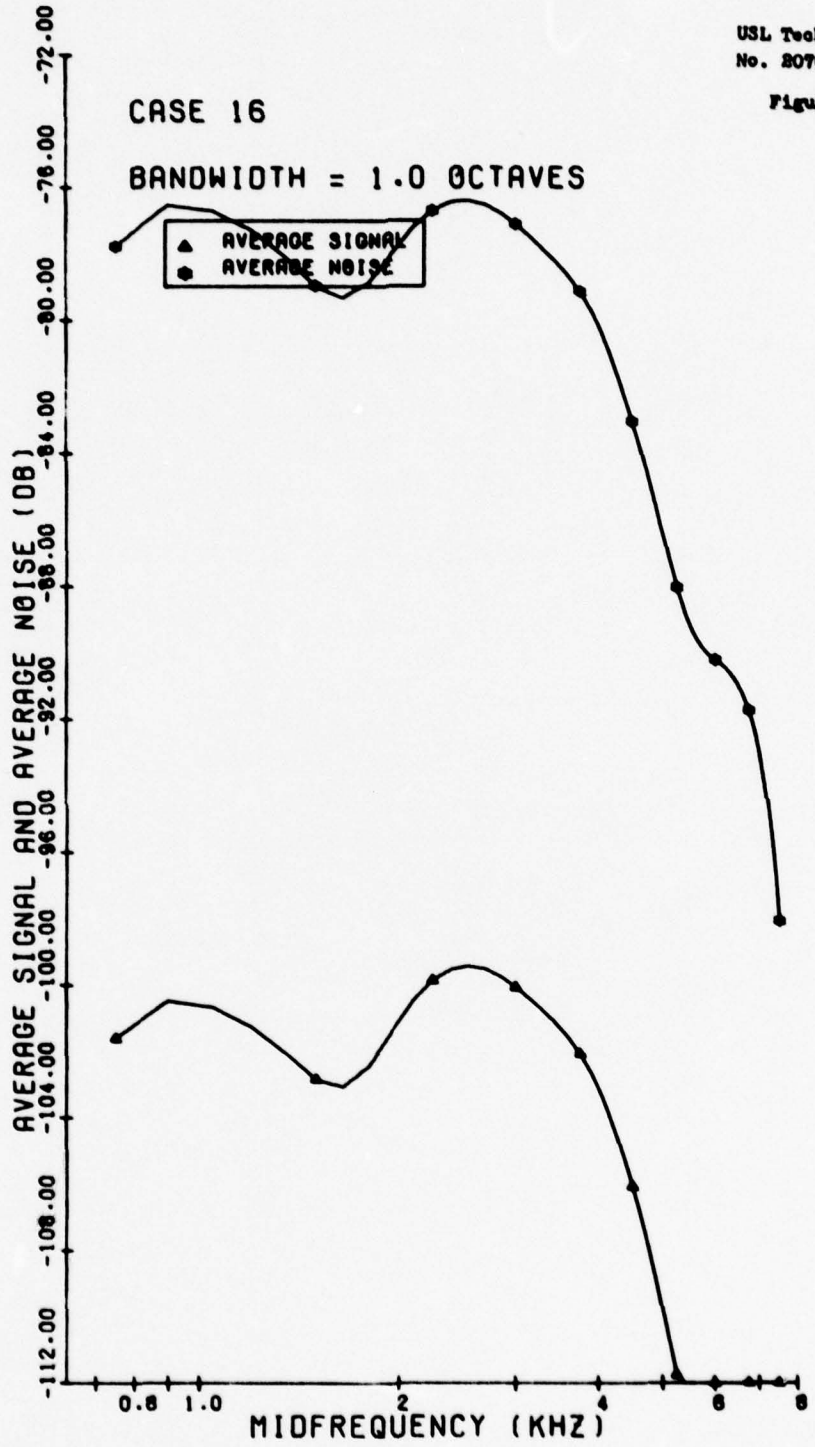
Figure 10



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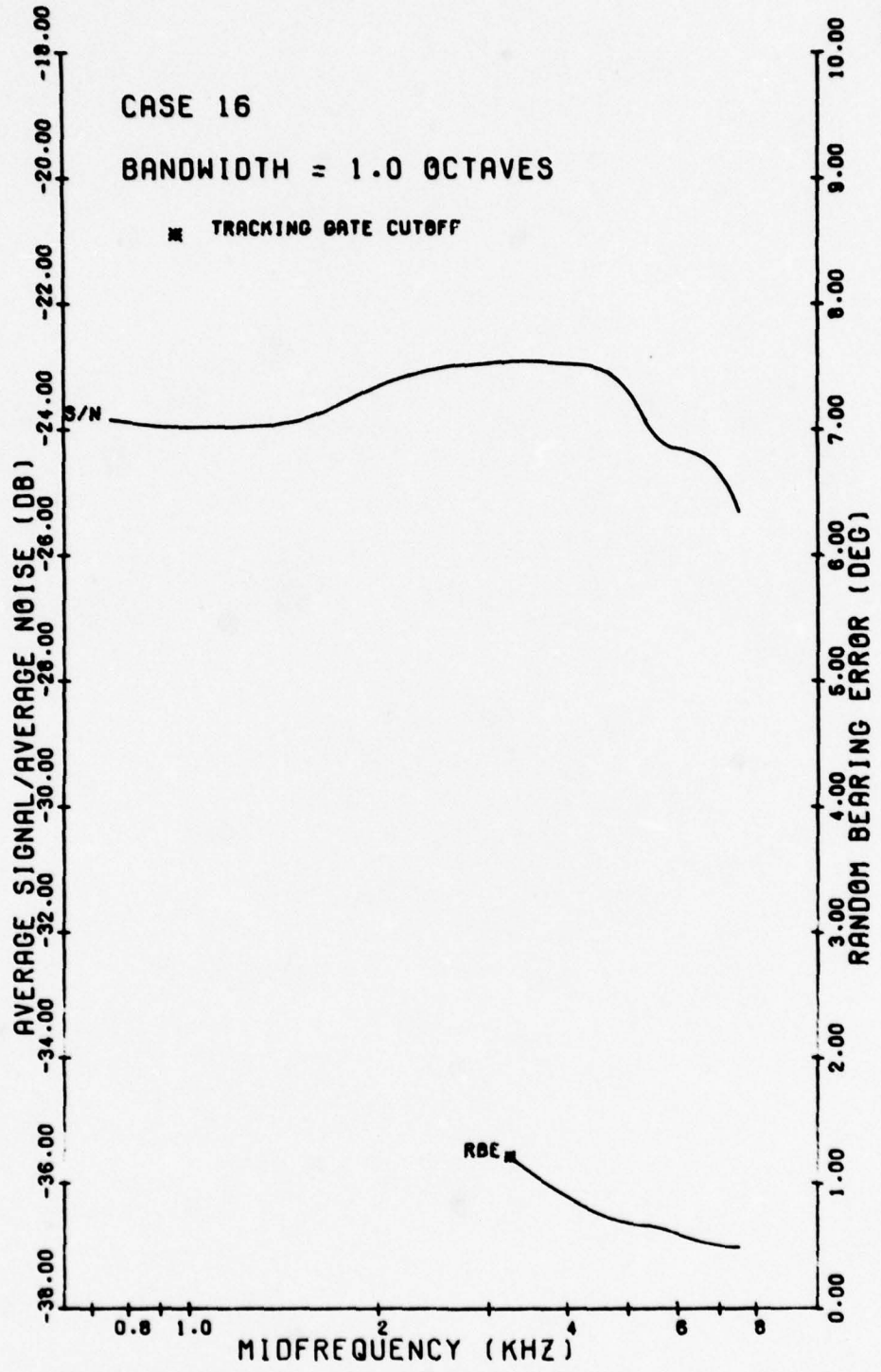
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BANDWIDTH = 1.0 OCTAVES
TRACKING GATE CUTOFF
S/N
RBE
AVERAGE SIGNAL/AVERAGE NOISE (DB)
-18.00
-20.00
-22.00
-24.00
-26.00
-28.00
-30.00
-32.00
-34.00
-36.00
-38.00
RANDOM BEARING ERROR (DEG)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.8
1.0
2
4
6
8
MIDFREQUENCY (KHZ)

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Figure 12

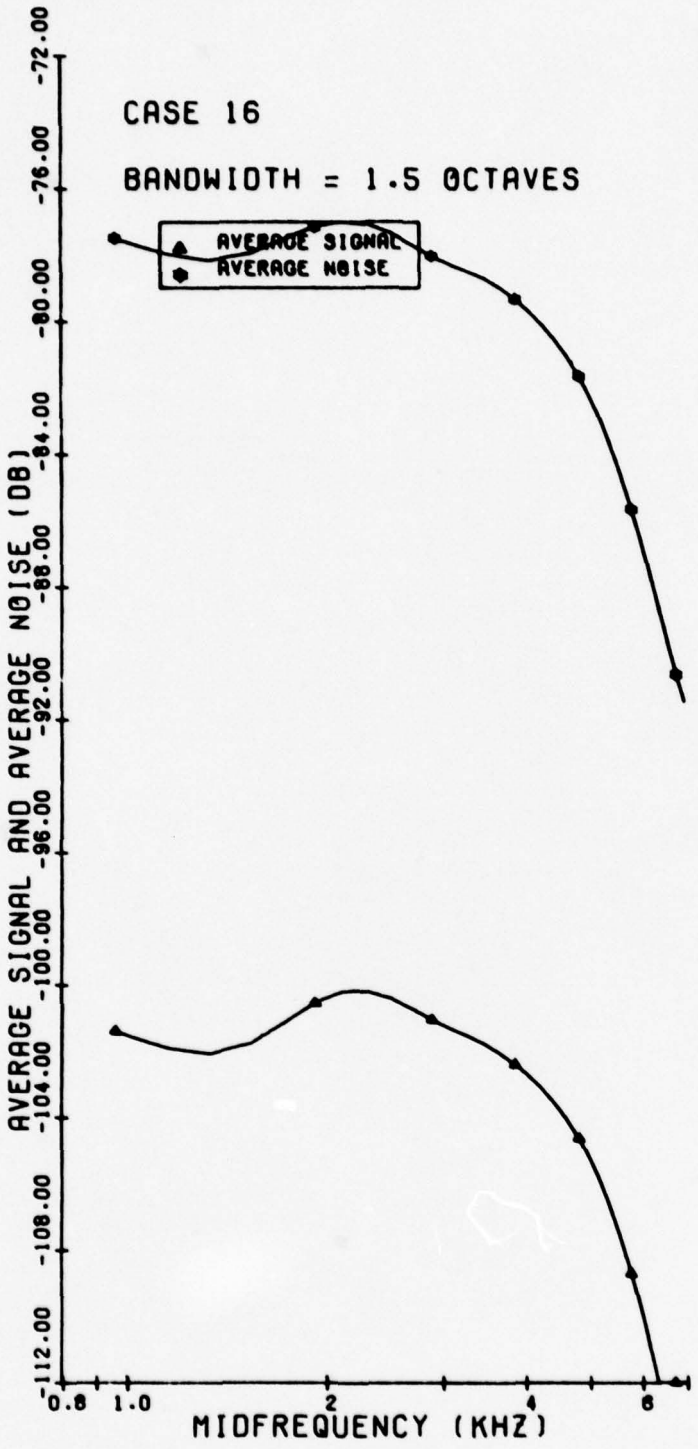

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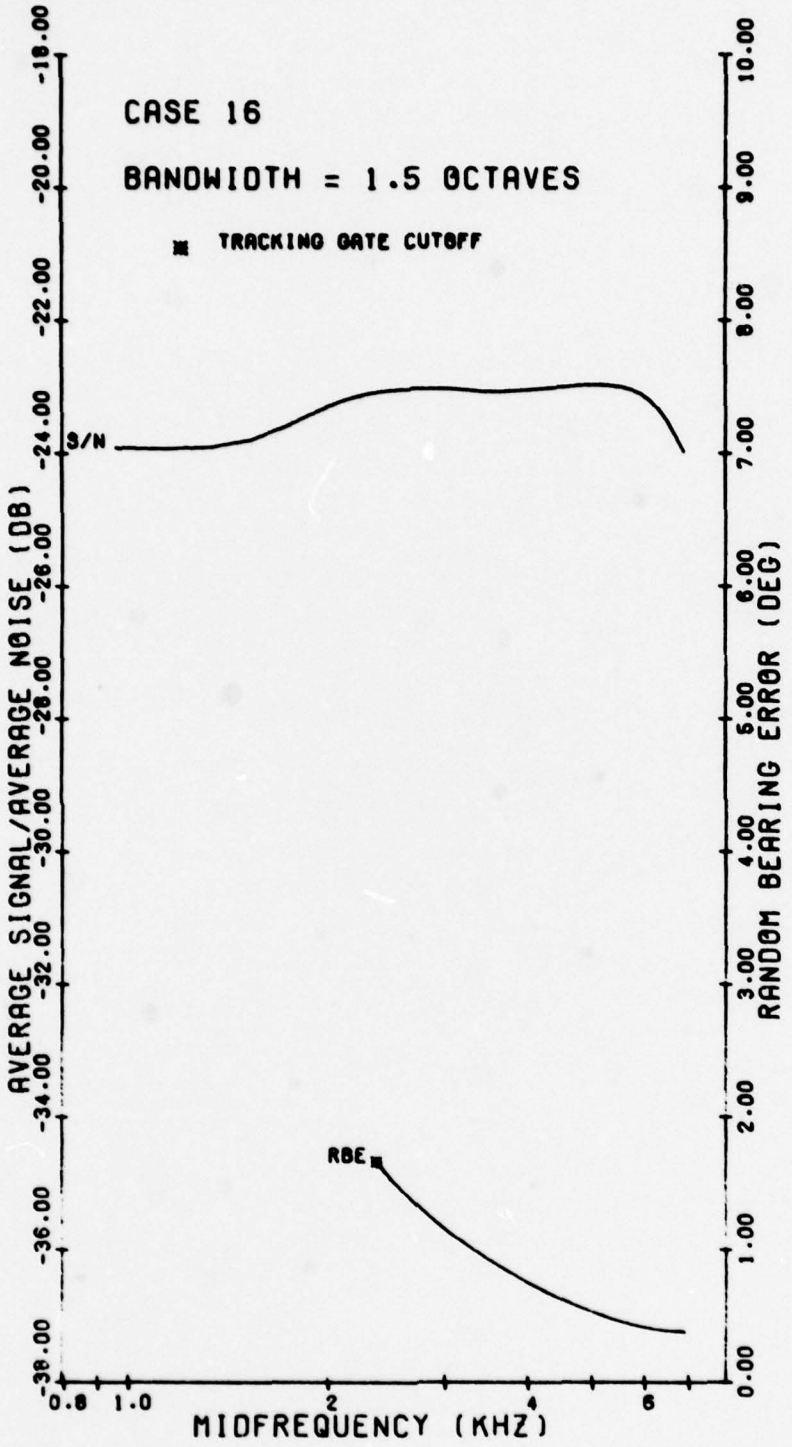
Figure 13



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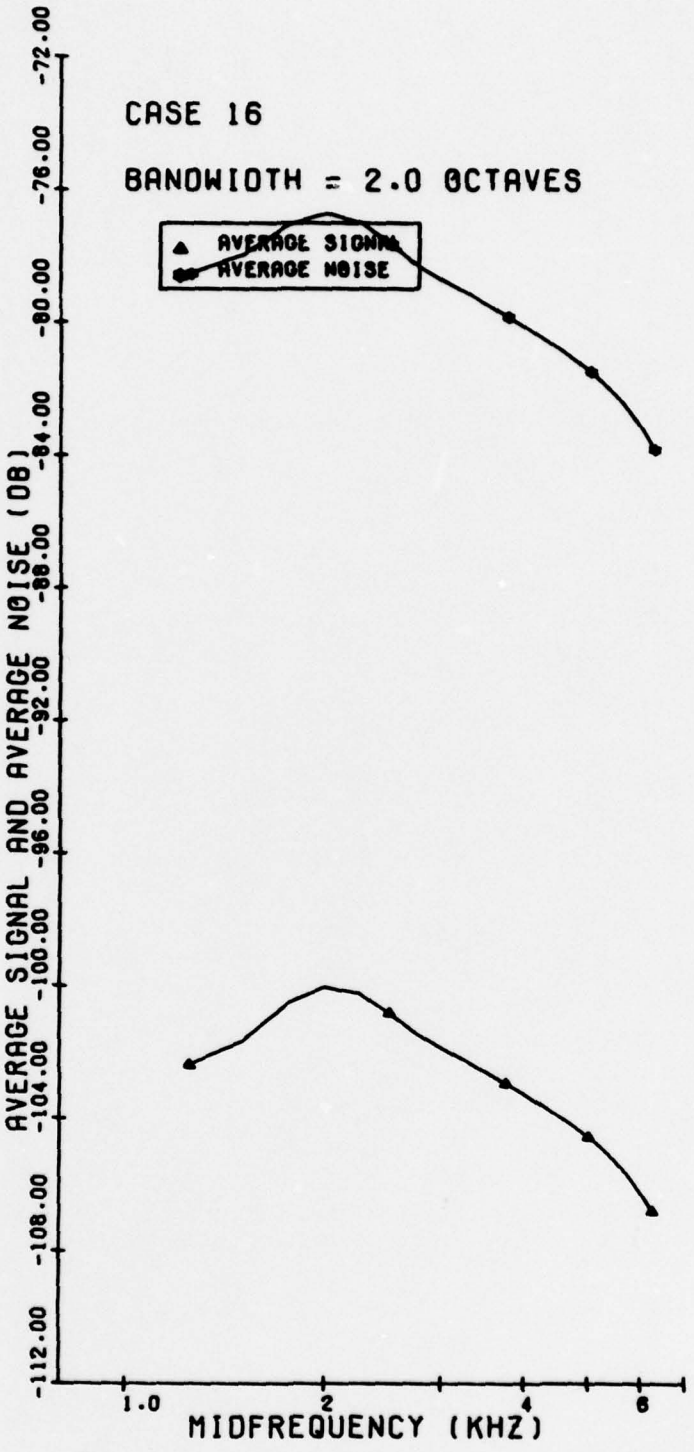
CASE 16
BANDWIDTH = 2.0 OCTAVES
AVERAGE SIGNAL
AVERAGE NOISE
AVERAGE SIGNAL AND AVERAGE NOISE (DB)
-72.00
-76.00
-80.00
-84.00
-88.00
-92.00
-96.00
-100.00
-104.00
-108.00
-112.00
1.0
2
4
6
MIDFREQUENCY (KHZ)

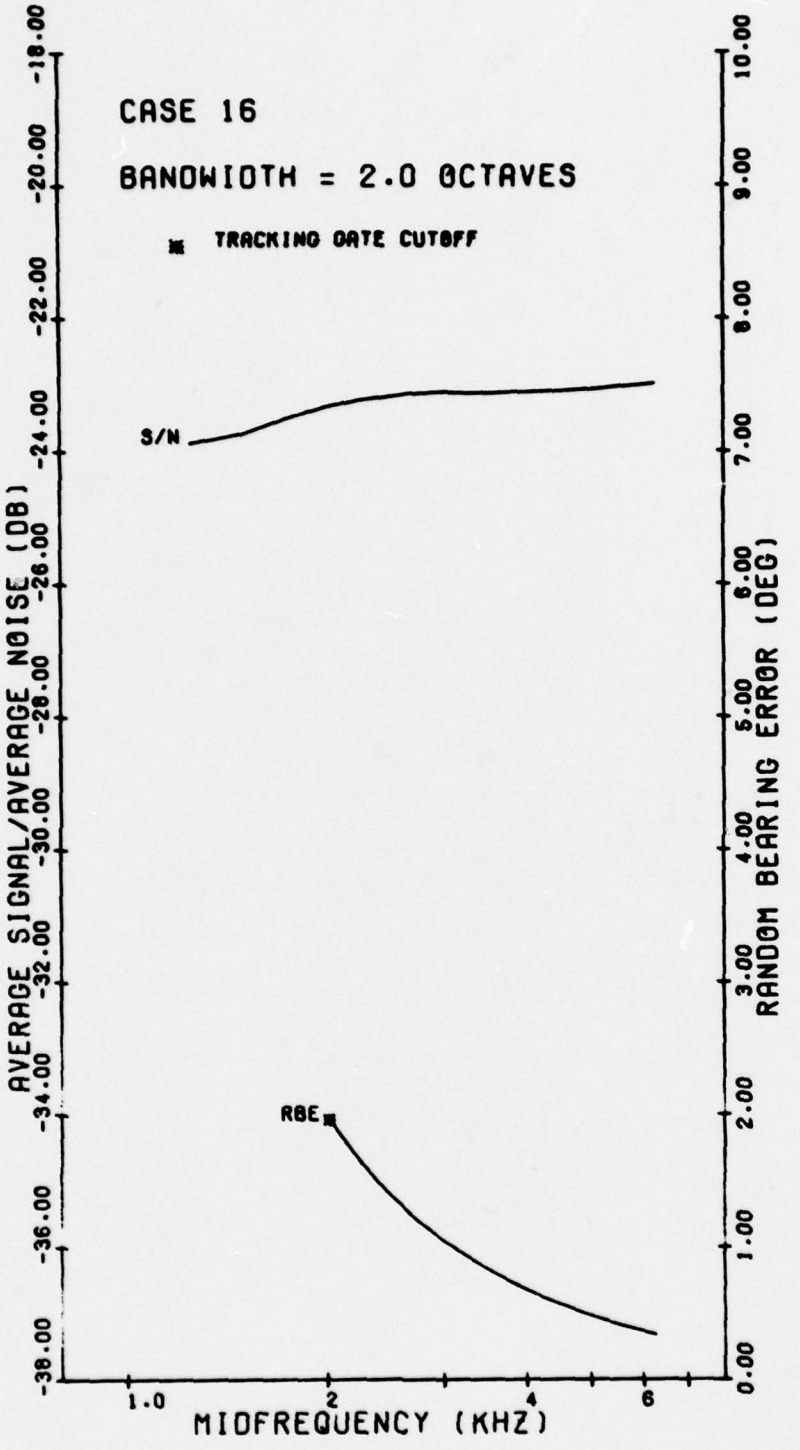
CASE 16
BANDWIDTH = 2.0 OCTAVES
TRACKING GATE CUTOFF
S/N
RBE
AVERAGE SIGNAL/AVERAGE NOISE (DB)
-18.00
-20.00
-22.00
-24.00
-26.00
-28.00
-30.00
-32.00
-34.00
-36.00
-38.00
RANDOM BEARING ERROR (DEG)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.0
2
4
6
MIDFREQUENCY (KHZ)

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Figure 16

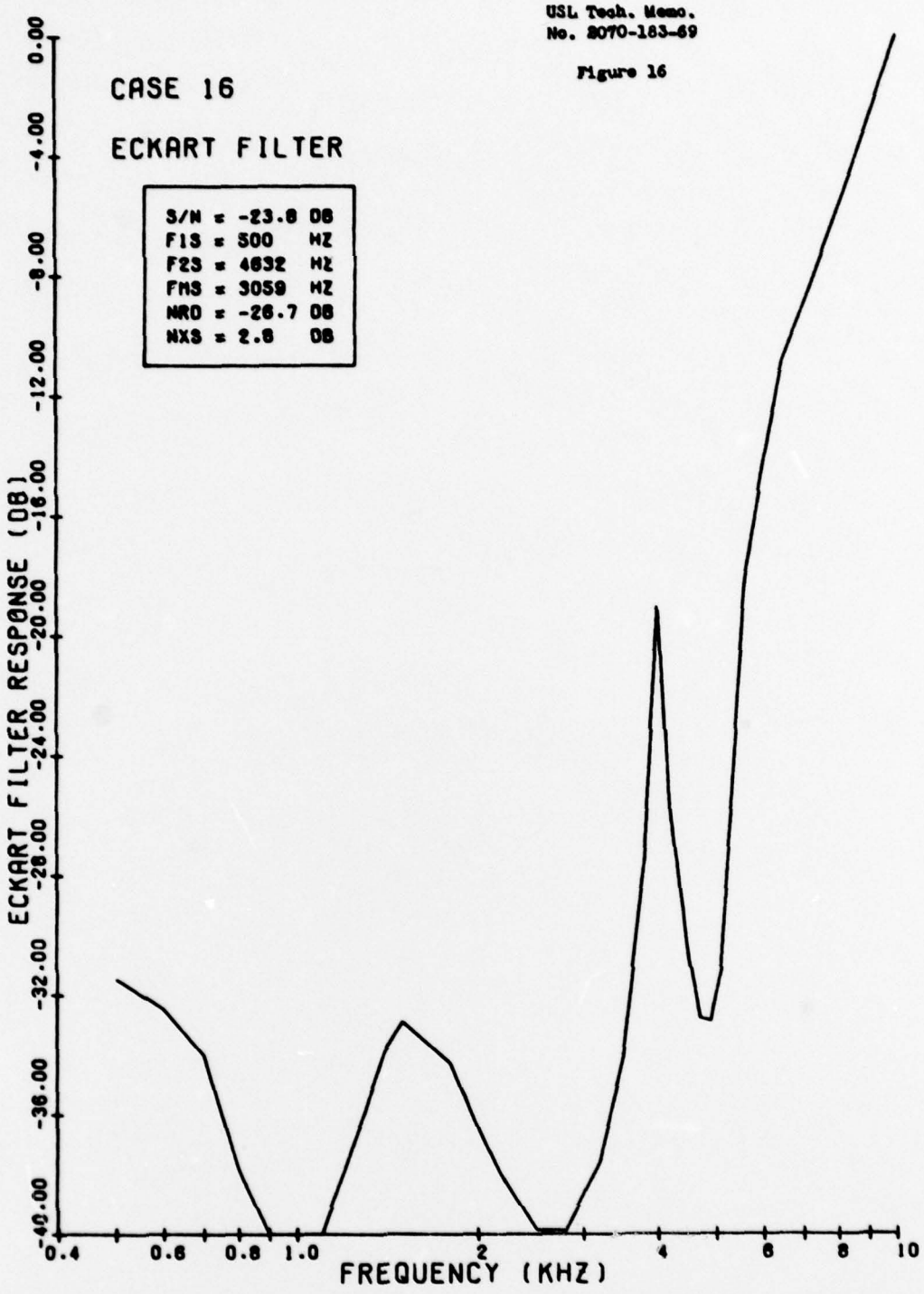

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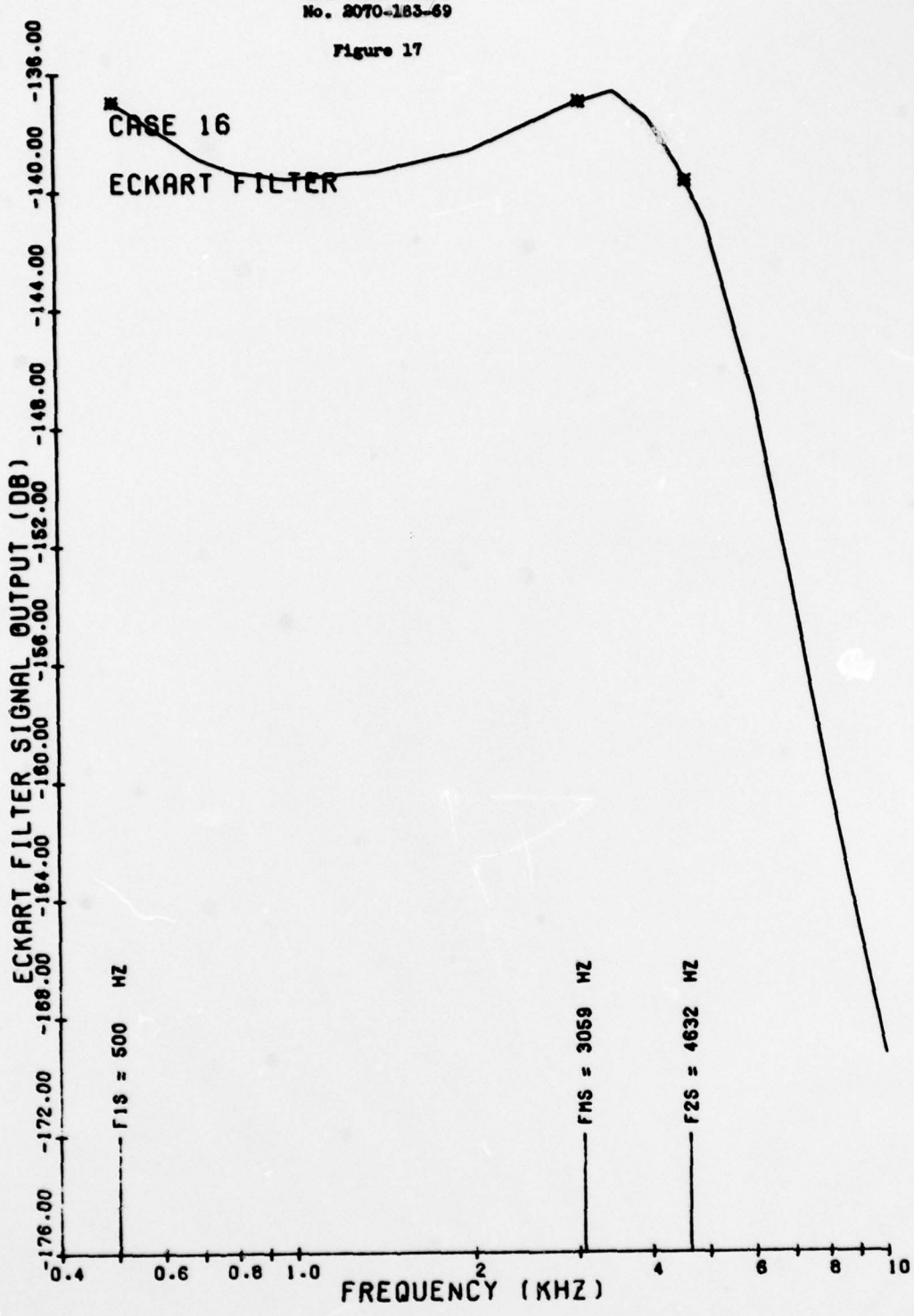
Figure 17



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APPENDIX A

INPUT DECK FOR CASE 16

```
$INPUT

      CASE = 16,

      FMIN=.5,  FMAX=10.0,  NFREQ=96,

      NFLAG = .FALSE.,

      FLS(1) = 1.0, 6.0,
      LS(1) = 14.7, 0.9,

      FLN(1)= .3,.5,.75,1.0,1.4,2.0,8.0,
      LN(1)= -36.0,-30.0,-36.5,-37.5,-39.0,-40.8,-50.8,

      FNW(1)= 1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,
      NW(1)= 92.0,96.0,98.8,101.0,103.2,105.6,108.2,111.0,

      FNDI(1)= .1,.14,.21,.3,.5,3.5,4.0,4.5,5.0,5.5,6.0,7.0,8.0,9.0,
      FNDI(15)=10.0,
      NDI(1)= 3.0,3.0,4.5,6.5,10.0,26.2,26.7,27.0,27.0,26.7,26.4,25.5,
      NDI(13)= 25.1,25.0,25.0,

      FNHS(1) = .3,.55,.7,.8,.9,1.0,1.1,1.3,1.4,1.5,1.8,2.2,2.5,2.8,3.2,
      FNHS(16) = 3.5,3.8,4.0,4.2,4.5,4.7,4.9,5.1,5.6,6.5,8.0,10.0,
      NHS(1) = -41.0,-36.0,-32.0,-27.0,-23.0,-21.0,-21.0,-23.0,-24.0,
      NHS(10) = -24.0,-20.0,-13.0,-9.0,-7.0,-7.0,-9.0,-15.0,-23.0,-16.0,
      NHS(26) = -11.0,-9.0,-9.0,-11.0,-25.0,-35.0,-44.0,-53.0,

      NLS=2,  NLN=7,  NNW=6,  NNDI=15,  NNHS=27,

      PLOTLS=1,  PLOTLN=1,  PLOTNW=1,  PLOTDI=1,  PLOTHS=1,
      LPLOTN=1,  LPLOTR=1,
      PLOTN=1,  PLOTAN=1,
      PLOTR=1,  PLOTAR=1,  PLOTLF=1,  PLOTES=1,

      MIN=1.0,   MAX=2.0,   DEL=0.5,

      C=4850.0,   D=4.7,   T=50.0,

      SKIP = .FALSE.,

      STOP = .TRUE.,

$END
```

FREQ DATA (KHZ)	SOURCE LEVEL (DB)
1.000	14.70
0.000	.00

FREQ DATA (KHZ)	NOISE LEVEL (DB)
.000	-36.00
.000	-36.00
.100	-36.00
1.000	-37.00
1.000	-39.00
2.000	-46.00
5.000	-50.00

FREQ DATA (KHZ)	PROPAGATION LOSS (DB)
1.000	92.00
2.000	96.00
3.000	98.00
4.000	101.00
5.000	103.00
6.000	105.00
7.000	108.00
8.000	111.00

FREQ DATA (KHZ)	DIRECTIVITY INDEX (DB)
.100	3.00
.200	3.00
.250	4.30
.300	6.30
.500	10.00
5.000	26.00
9.000	26.70
4.000	27.00
5.000	27.00
5.000	26.70
6.000	26.40
7.000	25.30
8.000	25.10
9.000	25.00
10.000	25.00

APPENDIX B

COMPLETE PRINTOUT FOR CASE 16

FREQ DATA (KHZ)	HYDROPHONE SENSITIVITY (DB)
.500	-41.00
.550	-36.00
.700	-32.00
.800	-27.00
.900	-23.00
1.000	-21.00
1.100	-21.00
1.300	-23.00
1.400	-24.00
1.500	-24.00
1.800	-20.00
2.000	-13.00
2.500	-9.00
2.800	-7.00
3.000	-7.00
3.500	-9.00
3.800	-15.00
4.000	-23.00
4.200	-16.00
4.300	-11.00
4.700	-9.00
4.900	-9.00
5.100	-11.00
5.600	-25.00
6.500	-35.00
8.000	-44.00
10.000	-53.00

COMBINED TABLE WILL HAVE 90 ROWS RANGING FROM .50 TO 10.00

CASE NUMBER 10

FREQ(KHZ)	LS(DB)	LN(DB)	NB(DB)	NCI(DB)	RMS(DB)	SIGNAL(DB)	NOISE(DB)	S/N(DB)
.500	17.50	-50.00	85.00	10.00	-36.79	-105.49	-82.79	-22.70
.600	16.09	-50.22	89.05	11.32	-34.56	-105.52	-82.30	-23.22
.700	17.07	-50.41	87.94	12.40	-32.00	-104.87	-81.22	-23.66
.800	16.16	-50.72	90.71	13.91	-27.00	-101.53	-77.64	-23.89
.900	15.90	-57.15	91.39	14.39	-23.00	-98.99	-75.03	-23.97
1.000	14.70	-57.50	92.00	15.77	-21.00	-98.30	-74.27	-24.03
1.100	14.07	-57.96	92.55	16.36	-21.00	-99.48	-75.49	-23.99
1.200	15.49	-58.31	93.05	17.29	-22.04	-101.60	-77.64	-23.96
1.300	16.98	-58.67	93.51	17.95	-23.00	-103.56	-79.62	-23.93
1.400	16.47	-59.00	93.94	18.57	-24.00	-105.47	-81.57	-23.90
1.500	16.01	-59.35	94.34	19.15	-24.00	-106.33	-82.49	-23.84
1.600	16.36	-59.67	94.71	19.68	-22.58	-105.72	-81.94	-23.77
1.700	16.16	-59.96	95.06	20.19	-21.25	-105.14	-81.42	-23.72
1.800	16.80	-60.27	95.39	20.66	-20.00	-104.59	-80.93	-23.66
1.900	16.99	-60.54	95.70	21.11	-18.11	-103.38	-79.77	-23.61
2.000	16.10	-60.80	96.00	21.54	-16.32	-102.22	-78.67	-23.56
2.100	9.78	-61.15	96.34	21.95	-14.62	-101.18	-77.72	-23.46
2.200	9.47	-61.49	96.66	22.33	-13.00	-100.19	-76.82	-23.37
2.300	9.17	-61.81	96.97	22.70	-11.61	-99.40	-76.12	-23.28
2.400	8.89	-62.16	97.26	23.06	-10.28	-98.65	-75.45	-23.19
2.500	8.62	-62.41	97.54	23.40	-9.00	-97.92	-74.81	-23.11
2.600	8.36	-62.69	97.81	23.73	-8.31	-97.76	-74.73	-23.04
2.700	8.11	-62.98	98.07	24.04	-7.64	-97.61	-74.65	-22.96
2.800	7.87	-63.23	98.32	24.34	-7.00	-97.46	-74.57	-22.89
2.900	7.65	-63.49	98.57	24.63	-7.00	-97.93	-75.11	-22.82
3.000	7.41	-63.72	98.80	24.92	-7.00	-98.39	-75.64	-22.75
3.100	7.19	-63.98	99.05	25.19	-7.00	-98.86	-76.15	-22.71
3.200	6.98	-64.19	99.29	25.45	-7.00	-99.31	-76.64	-22.67
3.300	6.78	-64.41	99.53	25.71	-7.69	-100.44	-77.81	-22.63
3.400	6.58	-64.63	99.76	25.96	-8.35	-101.53	-78.94	-22.59
3.500	6.39	-64.84	99.98	26.20	-9.00	-102.59	-80.04	-22.56
3.600	6.20	-65.04	100.19	26.31	-11.26	-105.05	-82.48	-22.65
3.700	6.02	-65.24	100.40	26.41	-13.05	-107.44	-84.78	-22.74
3.800	5.84	-65.43	100.61	26.51	-15.00	-109.77	-86.94	-22.83
3.900	5.67	-65.62	100.81	26.61	-19.05	-114.19	-91.27	-22.92
4.000	5.50	-65.80	101.00	26.70	-23.00	-118.50	-95.50	-23.00
4.100	5.34	-65.98	101.20	26.76	-19.46	-115.36	-92.20	-23.17
4.200	5.18	-66.15	101.48	26.82	-16.00	-112.30	-88.98	-23.33
4.300	5.02	-66.32	101.71	26.88	-14.29	-110.99	-87.50	-23.49
4.400	4.87	-66.49	101.94	26.94	-12.63	-109.70	-86.06	-23.64
4.500	4.72	-66.65	102.16	27.00	-11.00	-108.44	-84.65	-23.79
4.600	4.57	-66.81	102.38	27.00	-9.99	-107.79	-83.80	-24.00
4.700	4.43	-66.98	102.59	27.00	-9.00	-107.16	-82.96	-24.20
4.800	4.29	-67.14	102.80	27.00	-9.00	-107.51	-83.12	-24.39
4.900	4.15	-67.28	103.00	27.00	-9.00	-107.85	-83.26	-24.58
5.000	4.02	-67.41	103.20	27.00	-10.01	-109.19	-84.42	-24.77
5.100	3.89	-67.55	103.46	26.94	-11.00	-110.57	-85.49	-25.08
5.200	3.76	-67.69	103.72	26.88	-13.91	-113.86	-88.48	-25.39
5.300	3.63	-67.82	103.97	26.82	-16.76	-117.09	-91.40	-25.69
5.400	3.51	-67.96	104.21	26.76	-19.56	-120.26	-94.28	-25.98
5.500	3.39	-68.10	104.45	26.70	-22.30	-123.37	-97.10	-26.27
5.600	3.27	-68.23	104.69	26.64	-25.00	-126.42	-99.87	-26.56

5.700	3.15	-46.35	104.92	26.58	-26.19	-127.96	-101.12	-26.84
5.800	3.03	-46.48	105.15	26.52	-27.35	-129.47	-102.35	-27.12
5.900	2.92	-46.60	105.38	26.46	-28.50	-130.96	-103.56	-27.40
6.000	2.81	-46.72	105.60	26.40	-29.63	-132.42	-104.75	-27.67
6.100	2.70	-46.84	105.88	26.30	-30.74	-133.92	-105.89	-28.03
6.200	2.59	-46.96	106.15	26.21	-31.83	-135.39	-107.00	-28.39
6.300	2.49	-49.08	106.42	26.12	-32.90	-136.84	-108.09	-28.75
6.400	2.38	-49.19	106.69	26.02	-33.96	-138.27	-109.17	-29.09
6.500	2.28	-49.30	106.95	25.93	-35.00	-139.67	-110.23	-29.44
6.600	2.18	-49.41	107.21	25.84	-35.66	-140.69	-110.92	-29.78
6.700	2.08	-49.52	107.46	25.76	-36.31	-141.70	-111.59	-30.11
6.800	1.98	-49.63	107.71	25.67	-36.96	-142.69	-112.25	-30.44
6.900	1.88	-49.73	107.96	25.58	-37.59	-143.66	-112.91	-30.76
7.000	1.79	-49.84	108.20	25.50	-38.21	-144.63	-113.55	-31.08
7.100	1.69	-49.94	108.50	25.46	-38.83	-145.63	-114.22	-31.41
7.200	1.60	-50.04	108.79	25.42	-39.43	-146.62	-114.89	-31.74
7.300	1.51	-50.14	109.08	25.37	-40.03	-147.60	-115.54	-32.06
7.400	1.42	-50.24	109.37	25.33	-40.62	-148.57	-116.19	-32.38
7.500	1.33	-50.33	109.65	25.29	-41.20	-149.52	-116.83	-32.69
7.600	1.24	-50.43	109.92	25.25	-41.78	-150.46	-117.46	-33.00
7.700	1.15	-50.52	110.20	25.21	-42.34	-151.39	-118.08	-33.31
7.800	1.07	-50.62	110.47	25.18	-42.90	-152.30	-118.70	-33.61
7.900	.98	-50.71	110.74	25.14	-43.45	-153.21	-119.30	-33.91
8.000	.90	-50.80	111.00	25.10	-44.00	-154.10	-119.90	-34.20
8.100	.82	-50.89	111.26	25.09	-44.50	-154.94	-120.48	-34.46
8.200	.74	-50.98	111.52	25.08	-45.00	-155.78	-121.05	-34.72
8.300	.66	-51.07	111.77	25.07	-45.48	-156.60	-121.62	-34.98
8.400	.58	-51.15	112.02	25.06	-45.97	-157.41	-122.18	-35.24
8.500	.50	-51.24	112.27	25.05	-46.45	-158.22	-122.73	-35.49
8.600	.42	-51.32	112.52	25.04	-46.92	-159.01	-123.28	-35.74
8.700	.34	-51.41	112.76	25.03	-47.38	-159.80	-123.82	-35.98
8.800	.27	-51.49	113.00	25.02	-47.84	-160.58	-124.35	-36.22
8.900	.19	-51.57	113.24	25.01	-48.30	-161.34	-124.88	-36.46
9.000	.12	-51.65	113.47	25.00	-48.75	-162.10	-125.40	-36.70
9.100	.05	-51.73	113.70	25.00	-49.20	-162.85	-125.93	-36.93
9.200	-.03	-51.81	113.93	25.00	-49.64	-163.60	-126.45	-37.15
9.300	-.10	-51.89	114.16	25.00	-50.07	-164.33	-126.96	-37.37
9.400	-.17	-51.96	114.38	25.00	-50.50	-165.06	-127.47	-37.59
9.500	-.24	-52.04	114.60	25.00	-50.93	-165.78	-127.97	-37.80
9.600	-.31	-52.12	114.82	25.00	-51.35	-166.49	-128.47	-38.02
9.700	-.38	-52.19	115.04	25.00	-51.77	-167.19	-128.96	-38.23
9.800	-.45	-52.26	115.26	25.00	-52.19	-167.89	-129.45	-38.44
9.900	-.51	-52.34	115.47	25.00	-52.59	-168.58	-129.93	-38.65
10.000	-.58	-52.41	115.68	25.00	-53.00	-169.26	-130.41	-38.85

CASE NUMBER 10

FREQ(KHZ)	SIGNAL(LIN)	NOISE(LIN)	RATIO(LIN)
.500	.2067-10	.3269-08	.5370-02
.600	.2008-10	.3884-08	.4765-02
.700	.3[illegible]3-10	.7558-08	.4307-02
.800	.7028-10	.1723-07	.4079-02
.900	.1201-09	.3143-07	.4013-02
1.000	.1679-09	.3741-07	.3954-02
1.100	.1[illegible]7-09	.[illegible]-07	.3987-02
1.200	.6942-10	.1721-07	.4017-02
1.300	.4410-10	.1090-07	.4045-02
1.400	.2033-10	.6963-08	.4071-02
1.500	.2[illegible]-10	.5631-08	.4154-02
1.600	.2002-10	.6395-08	.4194-02
1.700	.3004-10	.7208-08	.4250-02
1.800	.3479-10	.8068-08	.4305-02
1.900	.4395-10	.1055-07	.4357-02
2.000	.5991-10	.1360-07	.4407-02
2.100	.7615-10	.1690-07	.4507-02
2.200	.9[illegible]-10	.2079-07	.4604-02
2.300	.1148-09	.2446-07	.4699-02
2.400	.1[illegible]-09	.2850-07	.4796-02
2.500	.1[illegible]-09	.3305-07	.4883-02
2.600	.1[illegible]-09	.3808-07	.4976-02
2.700	.1[illegible]-09	.4431-07	.5059-02
2.800	.1[illegible]-09	.5492-07	.5144-02
2.900	.1[illegible]-09	.5960-07	.5228-02
3.000	.1448-09	.2728-07	.5310-02
3.100	.1[illegible]-09	.2426-07	.5360-02
3.200	.1171-09	.2166-07	.5410-02
3.300	.9[illegible]-10	.1650-07	.5458-02
3.400	.7[illegible]-10	.1277-07	.5505-02
3.500	.5[illegible]-10	.9918-08	.5551-02
3.600	.3[illegible]-10	.5753-08	.5430-02
3.700	.1[illegible]-10	.[illegible]-08	.5320-02
3.800	.1[illegible]-10	.2024-08	.5213-02
3.900	.3[illegible]-11	.7458-09	.5110-02
4.000	.1[illegible]-11	.2818-09	.5012-02
4.100	.2[illegible]-11	.[illegible]-09	.4824-02
4.200	.5[illegible]-11	.1268-08	.4647-02
4.300	.7[illegible]-11	.1778-08	.4480-02
4.400	.1[illegible]-10	.2478-08	.4323-02
4.500	.1[illegible]-10	.3428-08	.4175-02
4.600	.1[illegible]-10	.4171-08	.3984-02
4.700	.1[illegible]-10	.5054-08	.3805-02
4.800	.1773-10	.4881-08	.3637-02
4.900	.1[illegible]-10	.4716-08	.3480-02
5.000	.1[illegible]-10	.3614-08	.3333-02
5.100	.8[illegible]-11	.2825-08	.3103-02
5.200	.4[illegible]-11	.1420-08	.2892-02
5.300	.1[illegible]-11	.7237-09	.2099-02
5.400	.9[illegible]-12	.3734-09	.2524-02
5.500	.4[illegible]-12	.1950-09	.2360-02
5.600	.2[illegible]-12	.1032-09	.2206-02

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PASSIVE S/N CALCULATIONS D. FREDERICK DATE 070769 USL Tech. Memo. No. 2070-183-69

5.700	.1099-14	.7720-10	.2068-02
5.800	.1147-14	.5819-10	.1940-02
5.900	.6918-13	.4402-10	.1821-02
6.000	.5768-13	.3346-10	.1712-02
6.100	.4937-13	.2579-10	.1573-02
6.200	.2090-13	.1990-10	.1446-02
6.300	.2274-13	.1551-10	.1335-02
6.400	.1490-13	.1210-10	.1232-02
6.500	.1178-13	.9474-11	.1138-02
6.600	.8926-14	.8095-11	.1053-02
6.700	.6709-14	.6934-11	.9755-03
6.800	.5365-14	.5953-11	.9048-03
6.900	.4001-14	.5122-11	.8397-03
7.000	.3447-14	.4417-11	.7804-03
7.100	.2734-14	.3781-11	.7230-03
7.200	.2175-14	.3244-11	.6705-03
7.300	.1736-14	.2784-11	.6225-03
7.400	.1390-14	.2403-11	.5785-03
7.500	.1117-14	.2075-11	.5384-03
7.600	.8993-15	.1795-11	.5011-03
7.700	.7264-15	.1555-11	.4671-03
7.800	.5883-15	.1356-11	.4357-03
7.900	.4778-15	.1179-11	.4068-03
8.000	.3890-15	.1023-11	.3804-03
8.100	.3203-15	.8953-12	.3578-03
8.200	.2644-15	.7847-12	.3369-03
8.300	.2207-15	.6888-12	.3175-03
8.400	.1849-15	.6056-12	.2995-03
8.500	.1557-15	.5336-12	.2826-03
8.600	.1325-15	.4706-12	.2669-03
8.700	.1147-15	.4156-12	.2522-03
8.800	.8760-16	.3672-12	.2385-03
8.900	.7390-16	.3252-12	.2257-03
9.000	.6203-16	.2884-12	.2137-03
9.100	.5203-16	.2555-12	.2029-03
9.200	.4370-16	.2267-12	.1928-03
9.300	.3690-16	.2014-12	.1834-03
9.400	.3122-16	.1794-12	.1746-03
9.500	.2643-16	.1596-12	.1658-03
9.600	.2246-16	.1423-12	.1578-03
9.700	.1910-16	.1270-12	.1503-03
9.800	.1627-16	.1135-12	.1433-03
9.900	.1388-16	.1010-12	.1366-03
10.000	.1186-16	.9100-13	.1303-03

PASSIVE S/N CALCULATIONS D. FREDERICK DATE 070769 PAGE USL Tech. Memo. No. 2070-183-69

CASE NUMBER 10

BANDWIDTH = 1.000 OCTAVES

MIDFREQ(KHZ)	F1(KHZ)	F2(KHZ)	AVERAGE SIGNAL(DB)	AVERAGE NOISE(DB)	AVE S/AVE N(DB)	BEARING ERROR(DEG)
.750	.500	1.000	-101.61	-77.78	-23.83	12.505
.900	.600	1.200	-100.47	-76.53	-23.94	9.670
1.050	.700	1.400	-100.66	-76.70	-23.97	7.699
1.200	.800	1.600	-101.25	-77.28	-23.97	6.303
1.350	.900	1.800	-102.04	-78.09	-23.95	5.265
1.500	1.000	2.000	-102.84	-78.97	-23.87	4.445
1.650	1.100	2.200	-103.06	-79.34	-23.72	3.768
1.800	1.200	2.400	-102.45	-78.91	-23.54	3.217
1.950	1.300	2.600	-101.41	-78.04	-23.37	2.784
2.100	1.400	2.800	-100.49	-77.24	-23.24	2.444
2.250	1.500	3.000	-99.86	-76.71	-23.15	2.172
2.400	1.600	3.200	-99.53	-76.45	-23.08	1.951
2.550	1.700	3.400	-99.43	-76.40	-23.03	1.768
2.700	1.800	3.600	-99.51	-76.52	-22.99	1.615
2.850	1.900	3.800	-99.75	-76.78	-22.97	1.485
3.000	2.000	4.000	-100.07	-77.11	-22.95	1.371
3.150	2.100	4.200	-100.42	-77.48	-22.93	1.270
3.300	2.200	4.400	-100.78	-77.87	-22.92	1.182
3.450	2.300	4.600	-101.16	-78.25	-22.91	1.104
3.600	2.400	4.800	-101.57	-78.66	-22.91	1.037
3.750	2.500	5.000	-102.07	-79.14	-22.93	.978
3.900	2.600	5.200	-102.67	-79.72	-22.95	.924
4.050	2.700	5.400	-103.38	-80.43	-22.95	.874
4.200	2.800	5.600	-104.20	-81.24	-22.96	.829
4.350	2.900	5.800	-105.11	-82.13	-22.99	.789
4.500	3.000	6.000	-106.07	-83.04	-23.03	.754
4.650	3.100	6.200	-107.11	-84.01	-23.09	.725
4.800	3.200	6.400	-108.24	-85.04	-23.19	.702
4.950	3.300	6.600	-109.43	-86.10	-23.33	.684
5.100	3.400	6.800	-110.60	-87.09	-23.51	.672
5.250	3.500	7.000	-111.76	-88.03	-23.73	.665
5.400	3.600	7.200	-112.77	-88.82	-23.95	.659
5.550	3.700	7.400	-113.49	-89.38	-24.11	.648
5.700	3.800	7.600	-114.00	-89.78	-24.22	.632
5.850	3.900	7.800	-114.32	-90.04	-24.28	.614
6.000	4.000	8.000	-114.51	-90.21	-24.30	.593
6.150	4.100	8.200	-114.68	-90.37	-24.32	.572
6.300	4.200	8.400	-114.93	-90.58	-24.35	.555
6.450	4.300	8.600	-115.26	-90.87	-24.39	.539
6.600	4.400	8.800	-115.69	-91.24	-24.45	.525
6.750	4.500	9.000	-116.27	-91.74	-24.53	.514
6.900	4.600	9.200	-117.05	-92.42	-24.63	.504
7.050	4.700	9.400	-118.10	-93.35	-24.75	.497
7.200	4.800	9.600	-119.46	-94.57	-24.89	.492
7.350	4.900	9.800	-121.19	-96.12	-25.07	.490
7.500	5.000	10.000	-123.36	-98.07	-25.30	.492

BANDWIDTH = 1.500 OCTAVES

MIDFREQ(KHZ)	F1,KHZ)	F2(KHZ)	AVERAGE SIGNAL(DB)	AVERAGE NOISE(DB)	AVE S/AVE N(DB)	BEARING ERROR(DEG)
.957	.500	1.414	-101.39	-77.49	-23.91	7.324
1.149	.600	1.697	-101.89	-77.96	-23.93	5.590
1.340	.700	1.980	-102.07	-78.17	-23.90	4.480
1.531	.800	2.263	-101.77	-77.97	-23.80	3.562
1.723	.900	2.546	-101.14	-77.54	-23.61	2.901
1.914	1.000	2.829	-100.54	-77.15	-23.39	2.397
2.106	1.100	3.111	-100.22	-77.01	-23.21	2.024
2.297	1.200	3.394	-100.17	-77.07	-23.10	1.748
2.488	1.300	3.677	-100.37	-77.32	-23.05	1.538
2.680	1.400	3.960	-100.71	-77.68	-23.03	1.372
2.871	1.500	4.243	-101.04	-78.02	-23.02	1.235
3.063	1.600	4.525	-101.31	-78.29	-23.02	1.121
3.254	1.700	4.808	-101.53	-78.50	-23.04	1.027
3.446	1.800	5.091	-101.77	-78.71	-23.06	.946
3.637	1.900	5.374	-102.06	-78.99	-23.07	.873
3.828	2.000	5.657	-102.39	-79.33	-23.06	.807
4.020	2.100	5.940	-102.74	-79.70	-23.04	.748
4.211	2.200	6.223	-103.13	-80.11	-23.03	.696
4.403	2.300	6.505	-103.56	-80.56	-23.01	.649
4.594	2.400	6.788	-104.06	-81.06	-22.99	.608
4.786	2.500	7.071	-104.62	-81.65	-22.98	.570
4.977	2.600	7.354	-105.27	-82.31	-22.97	.537
5.168	2.700	7.637	-106.00	-83.03	-22.96	.507
5.360	2.800	7.920	-106.82	-83.85	-22.97	.481
5.551	2.900	8.202	-107.73	-84.74	-22.99	.457
5.743	3.000	8.485	-108.69	-85.66	-23.03	.437
5.934	3.100	8.768	-109.73	-86.63	-23.10	.421
6.125	3.200	9.051	-110.86	-87.66	-23.20	.407
6.317	3.300	9.334	-112.05	-88.71	-23.34	.397
6.508	3.400	9.617	-113.22	-89.71	-23.51	.390
6.700	3.500	9.899	-114.38	-90.65	-23.73	.385
6.891	3.600	10.182	-115.39	-91.44	-23.95	.382

BANDWIDTH = 2.000 OCTAVES

MIDFREQ(KHZ)	F1(KHZ)	F2(KHZ)	AVERAGE SIGNAL(DB)	AVERAGE NOISE(DB)	AVE S/AVE N(DB)	BEARING ERROR(DEG)
1.250	.500	2.000	-102.39	-78.54	-23.86	4.346
1.500	.600	2.400	-101.68	-77.96	-23.72	3.240
1.750	.700	2.800	-100.55	-77.06	-23.49	2.485
2.000	.800	3.200	-100.03	-76.71	-23.32	1.982
2.250	.900	3.600	-100.20	-76.99	-23.22	1.636
2.500	1.000	4.000	-100.81	-77.65	-23.16	1.386
2.750	1.100	4.400	-101.42	-78.31	-23.11	1.192

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3.000	1.200	4.800	-104.85	-78.74	-23.10	1.005
3.250	1.300	5.200	-104.21	-79.09	-23.12	.929
3.500	1.400	5.600	-104.59	-79.47	-23.12	.851
3.750	1.500	6.000	-104.93	-79.83	-23.11	.788
4.000	1.600	6.400	-103.26	-80.16	-23.10	.678
4.250	1.700	6.800	-103.56	-80.49	-23.09	.619
4.500	1.800	7.200	-103.89	-80.81	-23.08	.567
4.750	1.900	7.600	-104.21	-81.14	-23.07	.522
5.000	2.000	8.000	-104.54	-81.48	-23.06	.482
5.250	2.100	8.400	-104.89	-81.85	-23.04	.447
5.500	2.200	8.800	-105.28	-82.25	-23.03	.416
5.750	2.300	9.200	-105.72	-82.71	-23.01	.388
6.000	2.400	9.600	-106.21	-83.21	-22.99	.363
6.250	2.500	10.000	-106.78	-83.80	-22.98	.341

CASE NUMBER 1C

ELKART FILTER

USL Tech. Memo.
No. 2070-183-69

FREQ(KHZ)	FILTER RESPONSE(DB)	SIGNAL OUTPUT(DB)	NOISE OUTPUT(DB)
.500	-31.47	-136.96	-114.26
.600	-32.40	-136.00	-114.78
.700	-34.00	-136.88	-115.22
.800	-37.02	-139.35	-115.45
.900	-40.50	-139.49	-115.52
1.000	-41.32	-139.62	-115.59
1.100	-40.00	-139.55	-115.55
1.200	-37.80	-139.48	-115.52
1.300	-35.87	-139.42	-115.49
1.400	-35.09	-139.37	-115.46
1.500	-32.96	-139.23	-115.40
1.600	-33.59	-139.41	-115.33
1.700	-32.85	-136.99	-115.27
1.800	-34.29	-136.88	-115.22
1.900	-33.46	-136.78	-115.17
2.000	-36.45	-136.68	-115.12
2.100	-37.30	-136.46	-115.02
2.200	-36.11	-136.30	-114.93
2.300	-36.72	-136.12	-114.84
2.400	-39.30	-137.95	-114.75
2.500	-39.80	-137.79	-114.67
2.600	-39.87	-137.63	-114.59
2.700	-39.67	-137.48	-114.52
2.800	-39.60	-137.33	-114.45
2.900	-39.20	-137.19	-114.38
3.000	-38.87	-137.06	-114.31
3.100	-38.16	-136.98	-114.27
3.200	-37.56	-136.90	-114.23
3.300	-36.36	-136.82	-114.19
3.400	-35.24	-136.74	-114.15
3.500	-34.06	-136.67	-114.12
3.600	-31.81	-136.86	-114.21
3.700	-29.80	-137.04	-114.30
3.800	-27.45	-137.22	-114.39
3.900	-25.20	-137.39	-114.48
4.000	-19.00	-137.56	-114.56
4.100	-22.50	-137.89	-114.73
4.200	-25.91	-136.42	-114.89
4.300	-27.50	-136.53	-115.05
4.400	-29.14	-136.84	-115.20
4.500	-30.70	-137.15	-115.35
4.600	-31.70	-137.35	-115.56
4.700	-32.79	-137.95	-115.70
4.800	-32.84	-140.34	-115.95
4.900	-32.66	-140.73	-116.14
5.000	-31.94	-141.10	-116.33
5.100	-31.15	-141.72	-116.64
5.200	-28.47	-142.34	-116.95
5.300	-25.04	-142.94	-117.25

5.400	-23.60	-143.52	-117.54
5.500	-20.73	-144.16	-117.83
5.600	-18.65	-144.68	-118.14
5.700	-17.20	-145.15	-118.40
5.800	-16.33	-145.60	-119.68
5.900	-15.39	-146.35	-119.96
6.000	-14.47	-146.69	-119.23
6.100	-13.71	-147.02	-119.59
6.200	-12.95	-148.34	-119.95
6.300	-12.21	-149.05	-120.30
6.400	-11.48	-149.75	-120.65
6.500	-10.76	-150.43	-121.00
6.600	-10.06	-151.11	-121.33
6.700	-10.00	-151.77	-121.67
6.800	-9.74	-152.43	-121.99
6.900	-9.41	-153.08	-122.32
7.000	-9.09	-153.71	-122.64
7.100	-8.74	-154.38	-122.97
7.200	-8.41	-155.03	-123.30
7.300	-8.07	-155.68	-123.62
7.400	-7.74	-156.31	-123.94
7.500	-7.42	-156.94	-124.25
7.600	-7.10	-157.56	-124.56
7.700	-6.78	-158.17	-124.87
7.800	-6.47	-158.78	-125.17
7.900	-6.16	-159.37	-125.47
8.000	-5.86	-159.96	-125.76
8.100	-5.54	-160.49	-126.02
8.200	-5.23	-161.01	-126.28
8.300	-4.92	-161.52	-126.54
8.400	-4.62	-162.03	-126.80
8.500	-4.32	-162.53	-127.05
8.600	-4.02	-163.03	-127.30
8.700	-3.72	-163.52	-127.54
8.800	-3.43	-164.01	-127.78
8.900	-3.15	-164.49	-128.02
9.000	-2.89	-164.96	-128.26
9.100	-2.56	-165.41	-128.49
9.200	-2.26	-165.86	-128.71
9.300	-1.97	-166.30	-128.93
9.400	-1.68	-166.74	-129.15
9.500	-1.39	-167.17	-129.36
9.600	-1.11	-167.60	-129.58
9.700	-.83	-168.02	-129.79
9.800	-.55	-168.44	-130.00
9.900	-.27	-168.85	-130.20
10.000	.00	-169.26	-130.41

AVERAGE SIGNAL/AVERAGE NOISE =-25.83 dB

FREQUENCY LIMITS

LOW FREQUENCY F&S = 500 Hz

HIGH FREQUENCY F&S = 4032 Hz

HIGH FREQUENCY F&S = 3059 Hz

RECOGNITION DIFFERENTIAL (RD) =-20.67 dB

SIGNAL EXCESS (SS) = 2.84 dB